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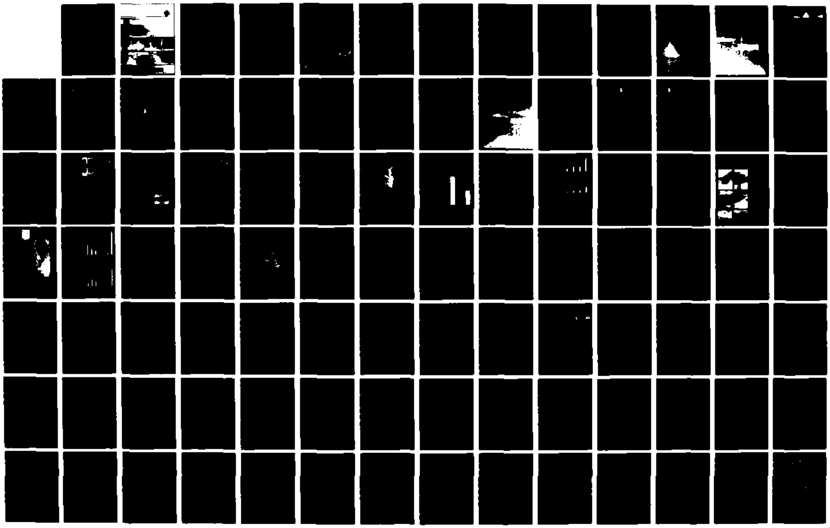

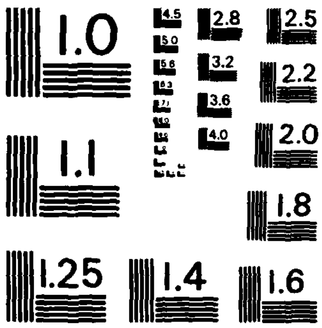

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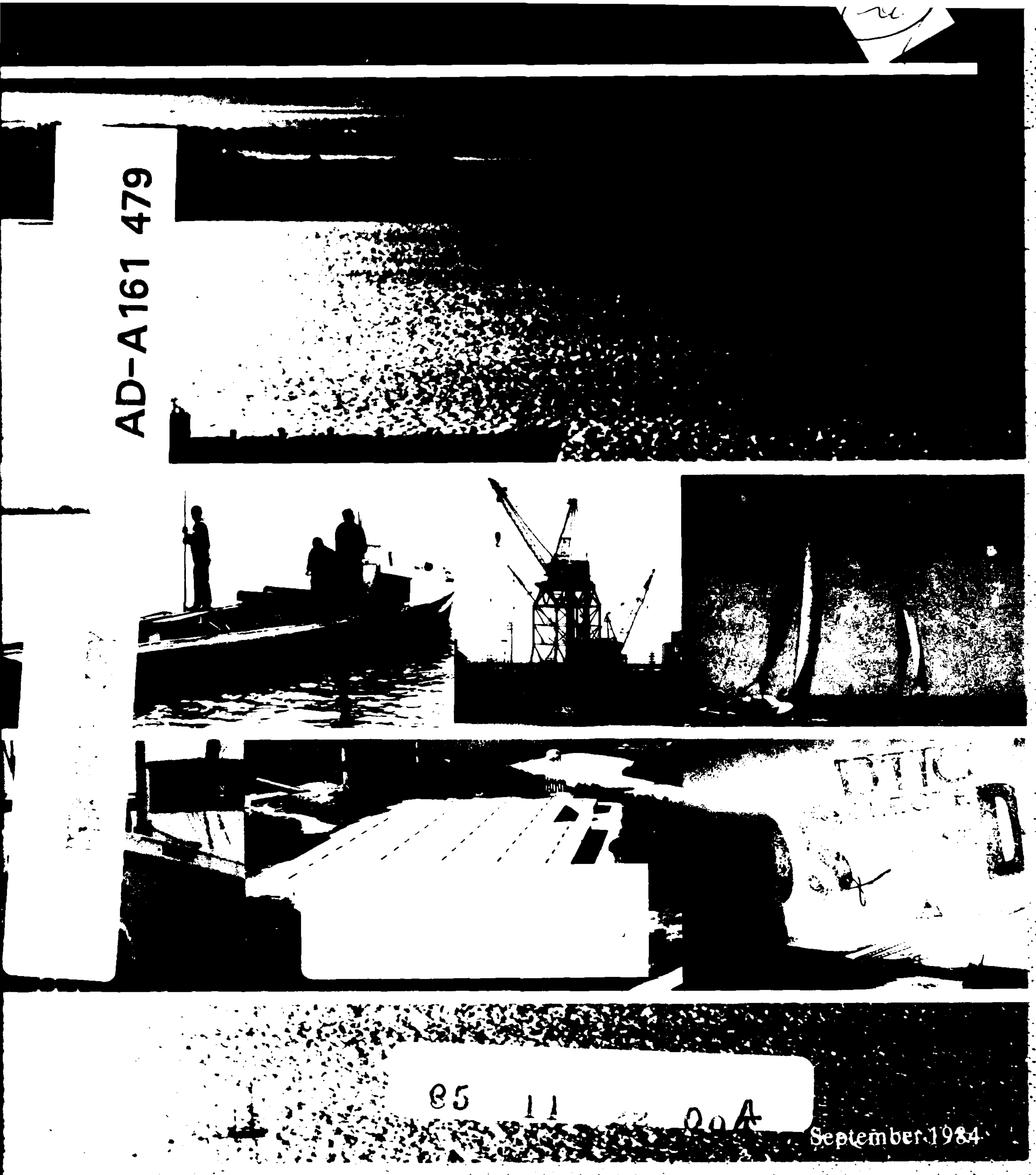

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
Chesapeake Bay is a complex estuarine system that is dependent on the freshwater inflow from its tributaries to maintain the salinity regime that characterizes its ecosystem.

Increasing population and economic growth in the Bay drainage area is predicted to result in increased water supply demands and attendant increases in the amount of water used consumptively. This will cause a marked reduction in freshwater inflow to the Bay and result in higher salinities throughout the Bay

20. ABSTRACT

system. In the long term, salinities would be expected to increase by as much as 2 to 4 ppt.

The Low Freshwater Inflow Study methodology involved selecting representative species for study, mapping potential habitat under various conditions, using expert scientists to interpret the significance of habitat change, and assessing socio-economic and environmental impacts of the changes.

While no specific plan was developed to solve the problems caused by reduced freshwater inflows, several alternatives were identified as "most promising". These include reservoir storage, conservation, growth restriction, oyster bed restoration, and fisheries management.

The final report recommends that a comprehensive water supply and drought management study be conducted that will identify those measures required to optimize the use of existing water supplies in the Bay drainage basin and minimize reductions in freshwater inflow to the Bay.

20

Chesapeake Bay Low Freshwater Inflow Study

MAIN REPORT

US Army Corps of Engineers
Baltimore District

September 1984

FOREWORD

This is one of the volumes comprising the final report on the Corps of Engineers' Chesapeake Bay Study. The report represents the culmination of many years of study of the Bay and its associated social, economic, and environmental processes and resources. The overall study was done in three distinct developmental phases. A description is provided below of each study phase, followed by a description of the organization of the report.

The initial phase of the overall program involved the inventory and assessment of the existing physical, economic, social, biological, and environmental conditions of the Bay. The results of this effort were published in a seven volume document titled *Chesapeake Bay Existing Conditions Report,* released in 1973. This was the first publication to present a comprehensive survey of the tidal Chesapeake and its resources as a single entity.

The second phase of the program focused on projection of water resource requirements in the Bay Region for the year 2020. Completed in 1977, the *Chesapeake Bay Future Conditions Report* documents the results of that work. The 12-volume report contains projections for resource categories such as navigation, recreation, water supply, water quality, and land use. Also presented are assessments of the capacities of the Bay system to meet the identified future requirements, and an identification of problems and conflicts that may occur with unrestrained growth in the future.

In the third and final study phase, two resource problems of particular concern in Chesapeake Bay were addressed in detail: low freshwater inflow and tidal flooding. In the Low Freshwater Inflow Study, results of testing on the Chesapeake Bay Hydraulic Model were used to assess the effects on the Bay of projected future depressed freshwater inflows. Physical and biological changes were quantified and used in assessments of potential social, economic, and environmental impacts. The Tidal Flooding Study included development of preliminary stage-damage relationships and identification of Bay communities in which structural and nonstructural measures could be beneficial.

The final report of the Chesapeake Bay Study is composed of three major elements: (1) Summary, (2) Low Freshwater Inflow Study, and (3) Tidal Flooding Study. The *Chesapeake Bay Study Summary Report* includes a description of the results, findings, and recommendations of all the above described phases of the Chesapeake Bay Study.

Summary Report
Supplement A—Problem Identification
Supplement B—Public Involvement
Supplement C—Hydraulic Model

The *Low Freshwater Inflow Study* consists of a Main Report and six supporting appendices. The report includes:

Main Report
Appendix A—Problem Identification
Appendix B—Plan Formulation
Appendix C—Hydrology
Appendix D—Hydraulic Model Test
Appendix E—Biota
Appendix F—Map Folio

The *Tidal Flooding Study* consists similarly of a Main Report and six appendices. The report includes:

Main Report
Appendix A—Problem Identification
Appendix B—Plan Formulation, Assessment and Evaluation
Appendix C—Recreation and Natural Resources
Appendix D—Social and Cultural Resources
Appendix E—Engineering, Design and Cost Estimates
Appendix F—Economics

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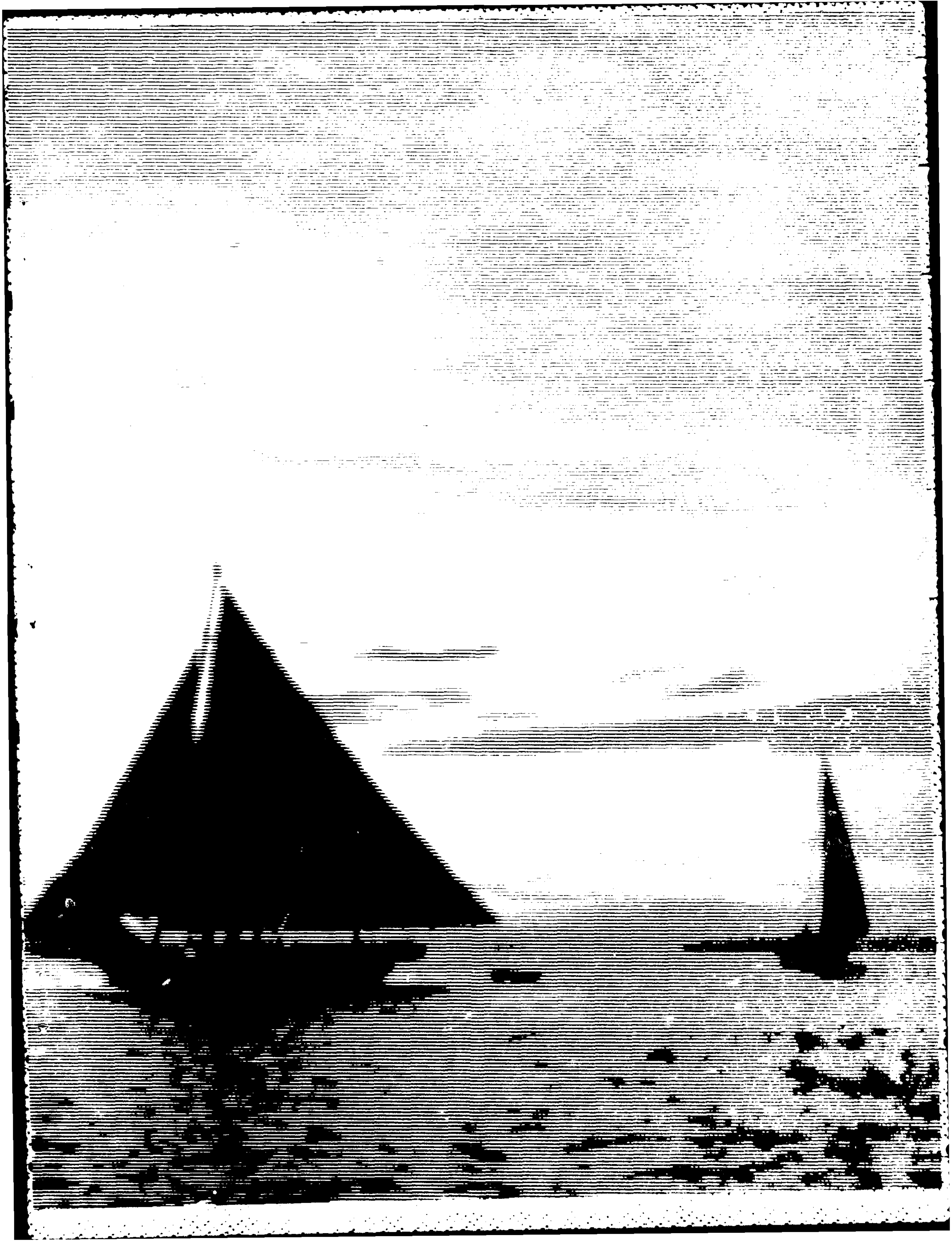
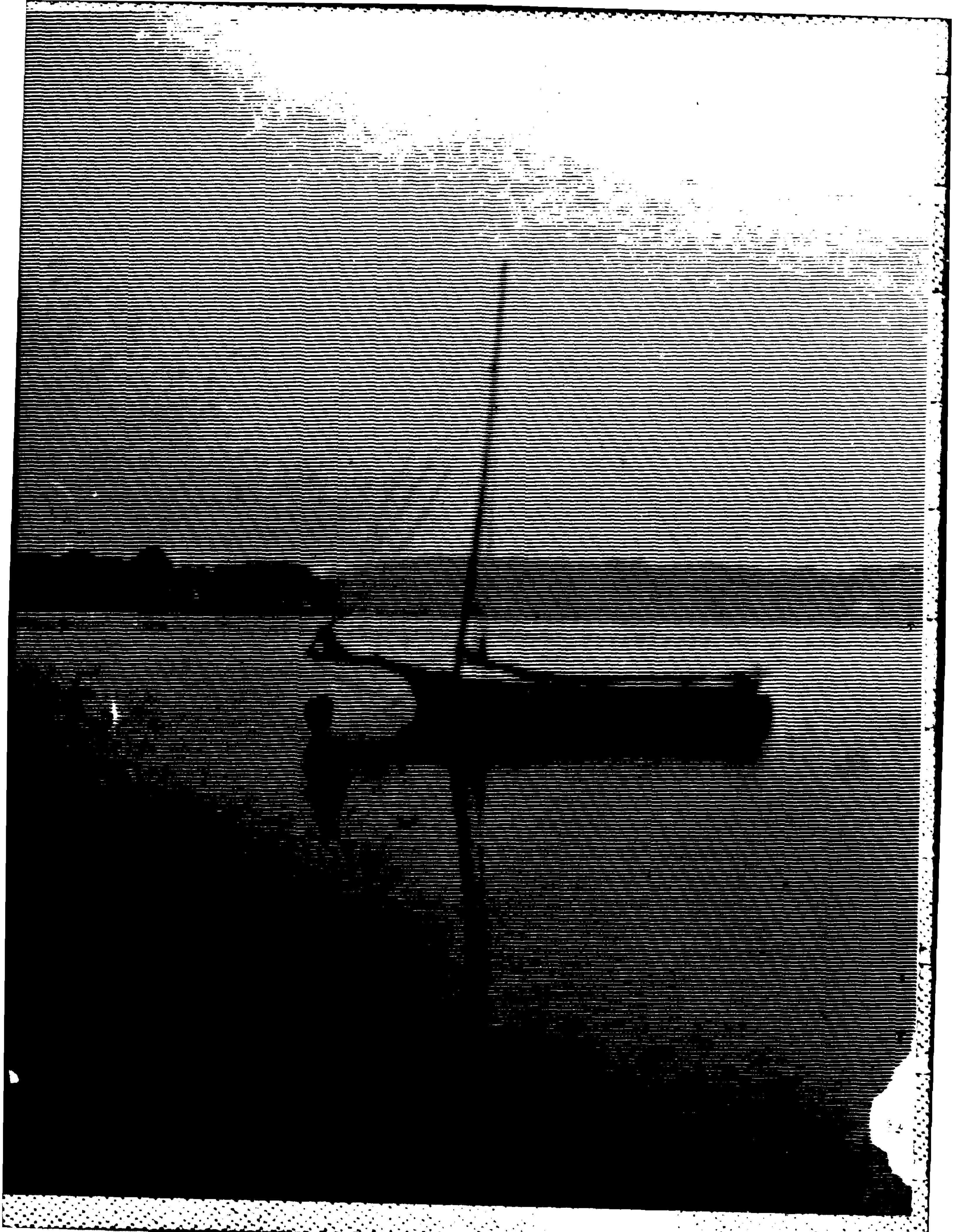
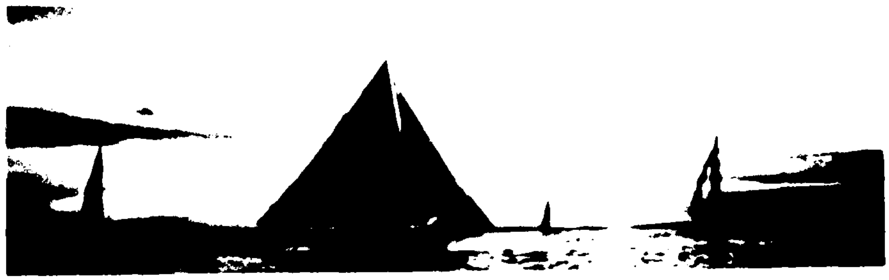




CHAPTER I



Introduction

Chesapeake Bay is a vast natural, economic, and social resource. Along with its tributaries, the Bay provides a transportation network on which much of the economic development of the region has been based, a wide variety of water-oriented recreational opportunities, a home for numerous fish and wildlife, a source of water supply for both municipalities and industries, and a site for the disposal of many of our waste products. The natural resources and processes of the Bay and man's activities interact to form a complex and interrelated system. Unfortunately, problems often arise when human use of one resource conflicts with either the natural environment or the use of another resource.

In 1970, approximately 7.9 million people lived in the Chesapeake Bay region. By the year 2020, population is expected to nearly double reaching a level of approximately 14.1 million persons. Employment is projected to grow at approximately the same rate as population; per capita income is projected to nearly quadruple; and manufacturing output is expected to steadily increase.

These increases in population, per capita income, and manufacturing output will cause additional demands to be placed on Chesapeake Bay's water and related land resources. It was the need for a plan to provide for the most efficient use of the Bay's resources that provided the impetus for the initiation of the Chesapeake Bay Study. Of particular concern in this report is the effects on Chesapeake Bay of future decreases in the amount of freshwater flowing into it from its tributaries.

Study Authority

The authority for the Chesapeake Bay Study and the construction of the Chesapeake Bay Hydraulic Model is contained in Section 312 of the River and Harbor Act of 1965, adopted 27 October 1965, which reads as follows:

(a) The Secretary of the Army, acting through the Chief of Engineers, is authorized and directed to make a complete investigation and study of water utilization and control of the Chesapeake Bay Basin, including the waters of the Baltimore Harbor and including, but not limited to, the following: navigation, fisheries, flood control, control of noxious weeds, water pollution, water quality control, beach erosion, and recreation. In order to carry out the purposes of this section, the Secretary, acting through the Chief of Engineers, shall construct, operate, and maintain in the State of Maryland a hydraulic model of the Chesapeake Bay Basin and associated technical center. Such model and center may be utilized, subject to such terms and conditions as the Secretary deems necessary, by any department, agency, or instrumentality of the Federal Government or of the States of Maryland, Virginia, and Pennsylvania, in connection with any research, investigation, or study being carried on by them of any aspect of the Chesapeake Bay Basin. The study authorized by this section shall be given priority.

(b) There is authorized to be appropriated not to exceed $6,000,000 to carry out this section.

An additional appropriation for the study was provided in Section 3 of the River Basin Monetary Authorization Act of 1970, adopted 19 June 1970, which reads as follows:

> In addition to the previous authorization, the completion of the Chesapeake Bay Basin Comprehensive Study, Maryland, Virginia, and Pennsylvania, authorized by the River and Harbor Act of 1965 is hereby authorized at an estimated cost of $9,000,000.

As a result of Tropical Storm Agnes, which caused extensive damage in Chesapeake Bay, Public Law 92-607, the Supplemental Appropriation Act of 1973, signed by the President on 31 October 1972, included $275,000 for additional studies of the impact of the storm on Chesapeake Bay.

Study Process—Chesapeake Bay Study

The Corps of Engineers' comprehensive study of Chesapeake Bay was accomplished in three distinct developmental phases. Each of these phases was responsive to one of the following stated objectives of the study program:

1. To assess the existing physical, chemical, biological, economic and environmental conditions of Chesapeake Bay and its related land resources.

2. To project the future water resources needs of Chesapeake Bay to the year 2020.

3. To formulate and recommend solutions to priority problems using the Chesapeake Bay Hydraulic Model.

The first objective was met through an inventory of Chesapeake Bay's water and related land resources and an identification of existing problems. The findings of this work were published in a seven-volume report titled *Chesapeake Bay Existing Conditions Report*. This was the first published report to present a comprehensive survey of the entire Bay Region and treat the Chesapeake Bay as a single entity. It contains much of the basic data required to project future demands on the Bay and to assess the ability of the resource to meet those demands.

The findings of the second or future projections phase of the program are provided in the 1978 *Chesapeake Bay Future Conditions Report*. The primary focus of that report was on the projection of water resources needs to the year 2020 and the identification of the problems and conflicts which would result from the unrestrained growth and use of the Bay's resources. The report, therefore, represented the completion of the

first iteration of the problem identification process. It provided the basic information necessary to do more detailed evaluations and to proceed into the problem solving phase of the program.

Two problems have been addressed in detail in the problem solving phase of the Chesapeake Bay Study. These are Tidal Flooding and Low Freshwater Inflow. This report presents the findings of the studies on the effects of low freshwater inflow to Chesapeake Bay.

Study Area

As shown in Figure 1-1, the Study Area for the Chesapeake Bay Study includes those counties or Standard Metropolitan Statistical Areas (SMSA) which are contiguous to or have a major socio-economic or environmental interaction with Chesapeake Bay.

The Low Freshwater Inflow Study also focuses on this area. All socio-economic and environmentally oriented analyses have addressed only this region as has the work on plan formulation. It was necessary, however, to address the entire Chesapeake Bay drainage basin (Figure 1-2) in computing future water consumption and the potentials for reductions in freshwater inflow. It was also necessary to address the entire basin in assessing whether it is technically reasonable to institute those most promising alternatives that involve flow supplementation measures.

Objectives of the Low Freshwater Inflow Study

Chesapeake Bay is dependent on the inflows of freshwater from its drainage basins to maintain the salinity regime that characterizes its ecosystem. The many species that live in the Bay year-round and others that utilize it only in various portions of their life cycle are generally able to thrive in the daily, seasonal, and yearly variations in salinity. However, increases in salinity caused by drastically reduced inflows during a drought period, or reductions in inflow of less drastic magnitudes over a longer period of time, can impose environmental stress. The health or even survival of aquatic organisms sensitive to particular levels of salinity can be threatened, and the spawning opportunity of certain other estuarine species could be limited. Periods of low freshwater inflow can also alter existing estuarine flushing characteristics and circulation patterns.

In addition to possible impacts on the Bay's biota, increases in salt concentrations may have serious implications to the municipalities and industries that are dependent upon the estuary as a source of water supply. In short, the character and uses of Chesapeake Bay are dependent on established physical, chemical, and biological patterns. These are intimately related to the volumes of freshwater inflows to the Bay and the seasonal variations in those flows.

In order to be fully responsive to these concerns, three objectives have been established for the Low Freshwater Inflow Study. These are:

1. To provide a better understanding of the relationship between the salinities in Chesapeake Bay and the magnitude of freshwater inflow from its tributaries.

2. To define the socio-economic and environmental impacts of both short and long term reductions of freshwater inflow.

3. To identify the most promising alternative solutions to the problems caused by reductions in freshwater inflow to Chesapeake Bay.

Planning Procedures and Scope

The initial stages of the Chesapeake Bay Low Freshwater Inflow Study were done under *The Principles and Standards for Planning Water and Related Land Resources* (P&S) issued by the Water Resources Council in 1973. These standards were superseded in March 1983 by the *Economic and Environmental Principles and Guidelines for Water and Related Land Resource Implementation Studies.* The final stages of the planning process incorporated the provisions of the latter document.

The Chesapeake Bay Low Freshwater Inflow Study was done in three major steps:

1. Problem Identification
2. Formulation of alternative plans.
3. Evaluation of alternative plans.

A diagram of the study process is shown on Figure 1-3. Much of the work involved in identifying the existing and future problems of Chesapeake Bay was done in the *Chesapeake Bay Existing Conditions Report* and *Future Conditions Report*. The work on these reports resulted in the identification of the importance of freshwater discharges to Chesapeake Bay in maintaining the socio-economic and environmental integrity of it. It also clearly identified that future freshwater inflows will be significantly reduced through consumptive use of water by municipalities, industries, and farmers.

The next step was oriented to clearly defining the magnitude of consumptive use of water expected in the year 2020 and its affects on the flow of freshwater into the Chesapeake Bay. The focus of the consumptive use evaluations was on the entire drainage basin of Chesapeake Bay. The data base adopted reflected Series E OBERS population and economic projections. Both water demand projections and rate of consumptive use were based on work done in state, local and other Federal studies.

A literature search was conducted to determine the hydrodynamic processes controlled or affected by freshwater inflows. It was found that there can be a correlation between freshwater inflow and salinity, water temperature, sediment inputs and rates, pollution input and dispersion, nutrient input and transport, and transport of non-motile aquatic organisms. It was determined, however, that the primary focus of the Low Freshwater Inflow Study should be on the changes in salinity resulting from droughts and consumptive losses of water. The factors that led to this conclusion were:

1. Salinity is one of the more important elements in the integrity of the aquatic life of Chesapeake Bay. Although there is still much that is unknown, there is sufficient knowledge of the salinity tolerances of many of the organisms to allow cause and effect analyses and intelligent planning. Most importantly, the changes in salinity caused by reduced freshwater inflow can be readily determined through tests on the hydraulic model.

2. The changes in estuarine velocities resulting from the decreasing inflow caused by consumptive losses were so small they could not be detected on the hydraulic model. It was therefore not

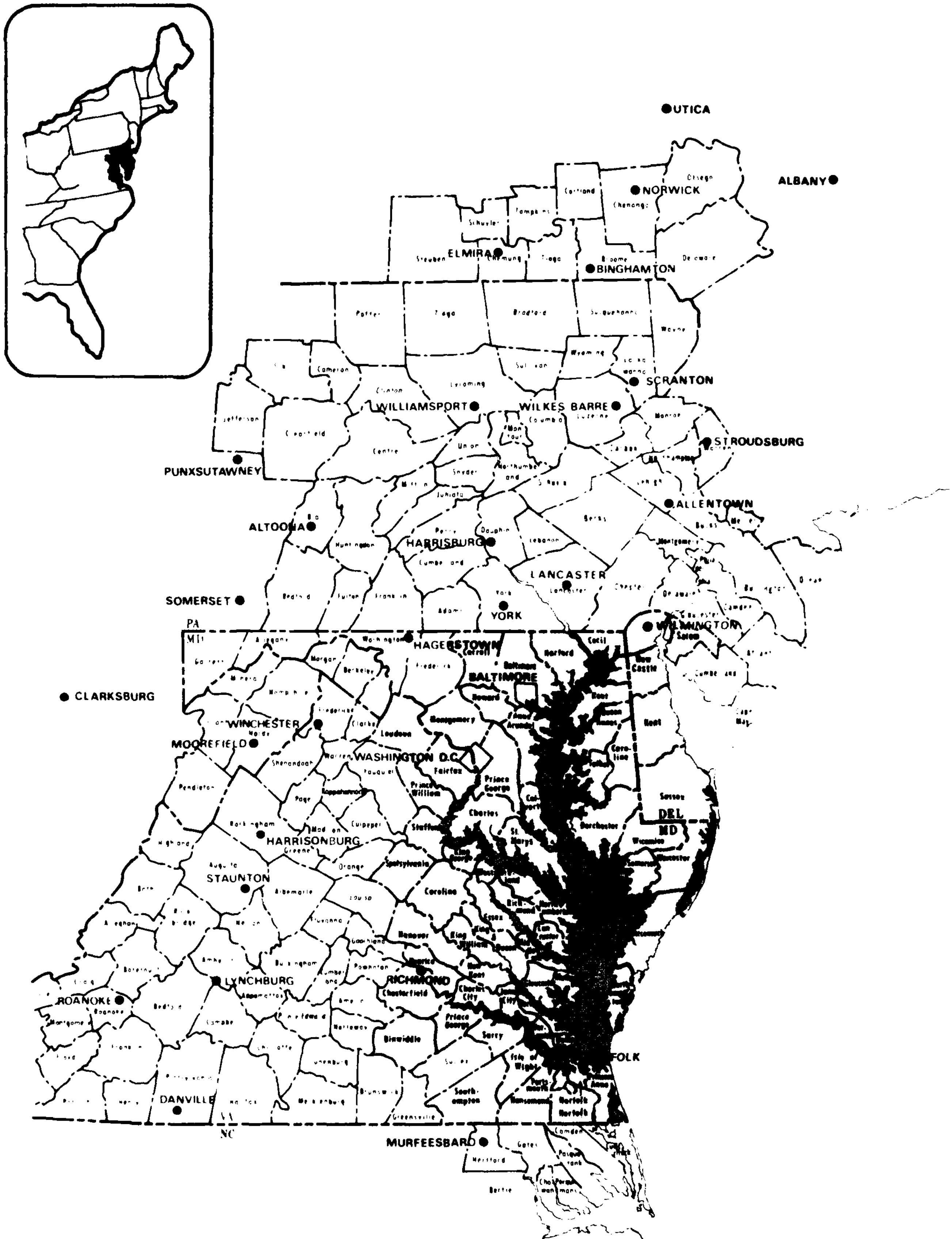


Figure I-1 Chesapeake Bay Study Area

possible to address the transport of non-motile organisms and the dispersion of pollutants, sediments and nutrients.

3. There will be little or no change in the quantity of pollutants, sediments and nutrients discharged into Chesapeake Bay as a result of consumptive losses. The quantity of these constituents contained in the waters coming into Chesapeake Bay are not directly related to the reduction in inflows caused by consumptive losses. Rather, they are primarily a function of storm water runoff, commercial and industrial activity and population changes.

4. At the present time, little is known about the processes associated with water temperature, the nutrient budget, the transport of non-motile organisms and the movement of sediment in the estuary. It is therefore not possible to develop the models needed to address these processes.

5. The 1972 amendments to the Water Pollution Control Act dictate a marked improvement in water quality. It has been assumed that, by the year 2020, the provisions of this act will have been met. Also water quality of Chesapeake Bay is being addressed in studies done by the Environmental Protection Agency.

The changes in Chesapeake Bay salinities caused by reduced freshwater inflows were determined through a test on the Chesapeake Bay Model (The Low Freshwater Inflow Problem Identification Test). This test provided the data needed to describe the existing and future salinity regime under average and drought freshwater inflow conditions. The 1960's drought was determined to be representative of severe low freshwater inflow conditions.

Identifying the affects of salinity changes on the biota of Chesapeake Bay was a complex and challenging endeavor. As far as could be determined, there were few, if any, precedences for this type of analysis. It was therefore necessary to do original work in this area. This was a cooperative effort among the firm of Western Eco-Systems Technology, Incorporated (WESTECH), the Steering Committee, the Fish and Wildlife Service and the Corps staff. The final procedures were simple, reflecting the rather large gaps in the present state of the art biological knowledge. There were several steps involved:

1. The identification of a small group of aquatic organisms which would be representative of the over 2700 different species indigenous to Chesapeake Bay. Through a cooperative effort with the Fish and Wildlife Service and the scientific community, 57 species were chosen.

2. Determining how the habitat for these 57 species is affected by changes in salinity. This was based on the salinity tolerances of the organisms and their requirements for substrate and water depth.

3. Translation of these habitat changes to biological impacts. This was done by the Fish and Wildlife Service in consultation with a panel of scientific experts (Biota Evaluation Panel). The state of the art knowledge of the biology of individual species and their interrelationship with other species is not sufficient to allow the use of numerical ecosystem models. This translation was therefore based on the experience and expertise of the panel members.

Concurrent with this work, an inventory was made of economic and social activities in the study area which might be affected either directly by increases in salinity (for instance municipal and industrial water supply) or indirectly by the relationship of the health of the Bay's ecosystem (the seafood and harvesting sectors). The magnitude and duration of the impacts associated with changes in salinity were assessed at a reconnaissance level.

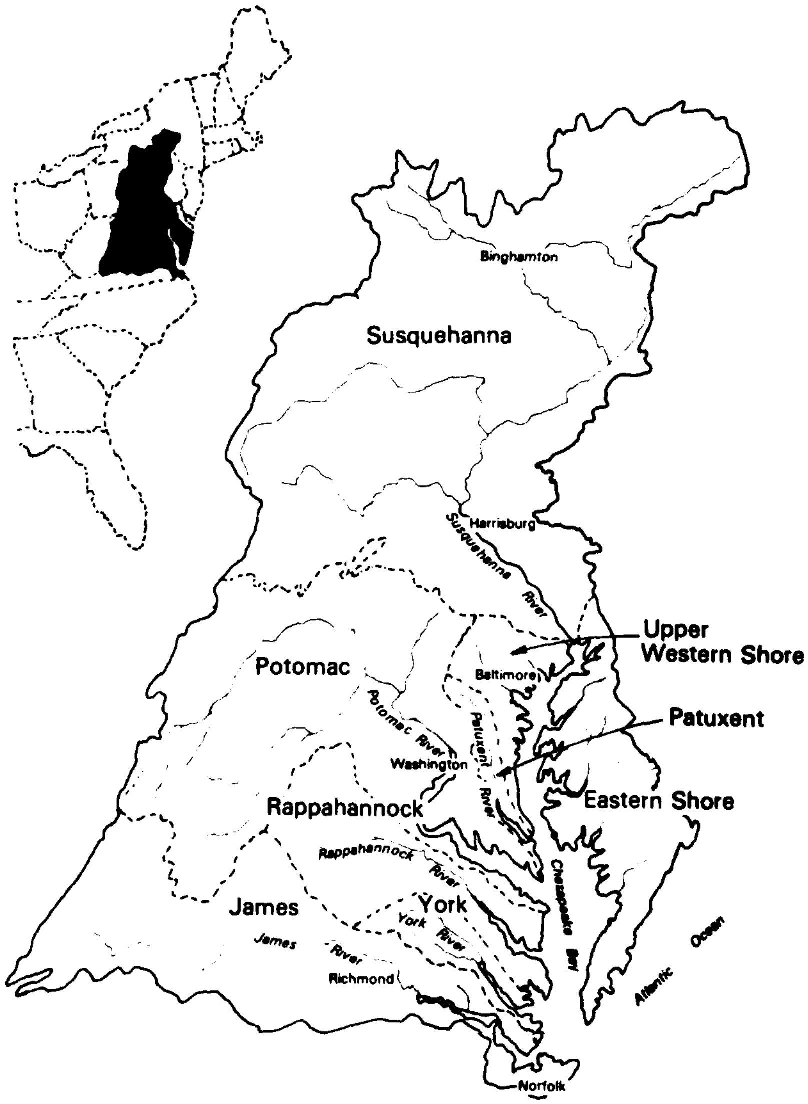


Figure 1-2 Chesapeake Bay Drainage Basin

In most cases it was not possible to express economic impacts in dollar values, as the state of the art knowledge of population dynamics is not sufficient to allow, with a high degree of assurance, the translation of habitat changes into changes in plant and animal populations. An attempt was made, however, to determine the dollar value of change in commercial fishing activity. In doing this, it was assumed that, over time there is a direct relationship between habitat and catch. Although this relationship cannot be verified, it does serve as a means to prioritize habitat change in terms of the relative economic values of the species.

The institutional analysis is of a preliminary scope. It identifies the political and legal climate as they relate to possible implementation of flow supplementation plans for major Bay tributaries. This analysis focused on the entire drainage basin of Chesapeake Bay.

The foregoing work served to specifically define the existing and potential future problems of Chesapeake Bay caused by both short and long term reductions in freshwater inflow. It also set the stage for beginning the plan formulation process. Plan formulation was an iterative process oriented to early identification of the most promising solutions to problems caused by decreasing quantities of freshwater inflow to Chesapeake Bay. Both structural and management measures were considered. The level of detail of the analysis was refined as the number of alternatives were narrowed. The plan formulation work was at a reconnaissance level of detail.

Public Involvement Program

An active and well planned public involvement program is required in order to effectively carry out a planning effort. The program conducted for the Chesapeake Bay Study is described in detail in Supplement B to the *Summary Report*.

The "public" is defined as any affected or interested non-Corps of Engineers entity, including Federal, regional, state, and local government entities and officials; public and private organizations; and individuals. Public involvement has played an important role in the overall Bay study program. The policy has been to fully inform the public about the study and to encourage meaningful participation in the planning process.

The specific objectives of the public involvement program were to:

a. Identify the agencies, institutions, organizations, and individuals that are affected by and interested in the Bay's resources.

b. Inform the public on the purpose and objectives of the Chesapeake Bay Study as well as all study developments and recommendations.

c. Obtain and incorporate when necessary, the public's comments, views, and perceptions of the problems, needs, and opportunities.

d. Identify public participation and information activities which may prove useful in achieving the objectives of the public involvement program. The depth of public participation during the study has varied with the type of public.

Because of the large size of the Chesapeake Bay Region and the complex problems which face the estuary, a large number of Federal, state, and local agencies and interstate commissions are involved in various aspects of water resource management in the region. The Federal concern with natural resources is founded on the fact that these resources form the basis for much of our national wealth and future well-being. The concern for water resources, in particular, is shown by many legislative enactments by the Congress. A continually developing body of law has established varying degrees of national concern as evidenced by the existence of

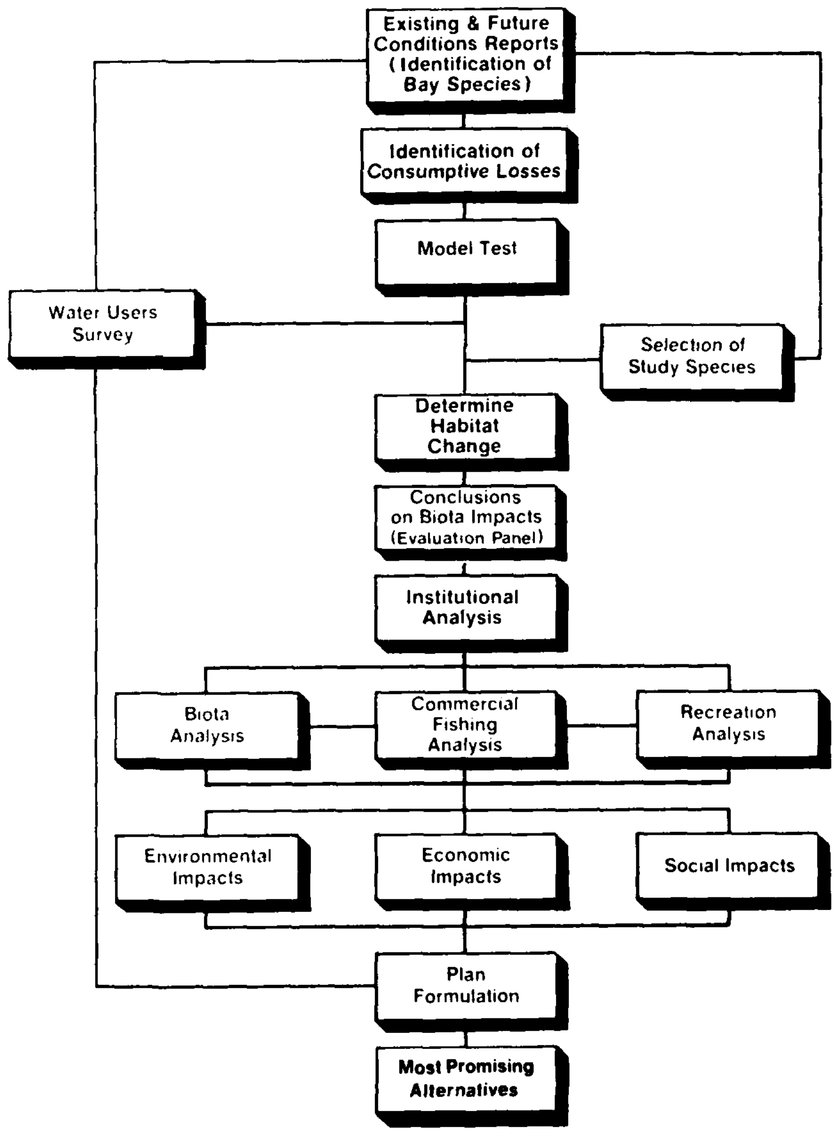


Figure I-3 Study Process

numerous Federal agencies with authority in such areas as navigation, flood control, drainage, irrigation, recreation, fish and wildlife conservation, water supply, and water quality.

Water resources management is not the exclusive domain of the Federal Government. State and local governments play an equally vital role. Such governments often have their own management and construction programs, as well as the responsibility to review and comment on proposed Federal projects. They are also an invaluable source of information due to their detailed knowledge of the areas within their jurisdiction. The states usually have one major executive level department responsible for natural resources. However, there are often additional state agencies and commissions in charge of certain aspects of water resources management outside of this organizational structure.

In addition to the Federal, state and local agencies, there are three interstate organizations which are directly involved in water resources management in the Chesapeake Bay region: the Susquehanna River Basin Commission, the Chesapeake Bay Commission, and the Interstate Commission on the Potomac River Basin.

The magnitude of the Chesapeake Bay Study, the large number of participants, and the complex spectrum of problems to be analyzed requires intensive coordination of these activities. The initial planning of this study was coordinated with the then National Council of Marine Resources and Engineering Development through its Committee on Multiple Use of the Coastal Zone.

This study was conceived as a coordinated partnership among Federal, state, and local agencies and interested scientific institutions. Each involved agency was charged with exercising leadership and reviewing and commenting on work performed by others. To realize these ends, the Advisory Group, Steering Committee, and five Task Groups, shown in Figure I-4, were established. The overall management of the Chesapeake Bay Study was the responsibility of the District Engineer of the Baltimore District, Corps of Engineers.

The Advisory Group, established in 1967, was the principal coordinating

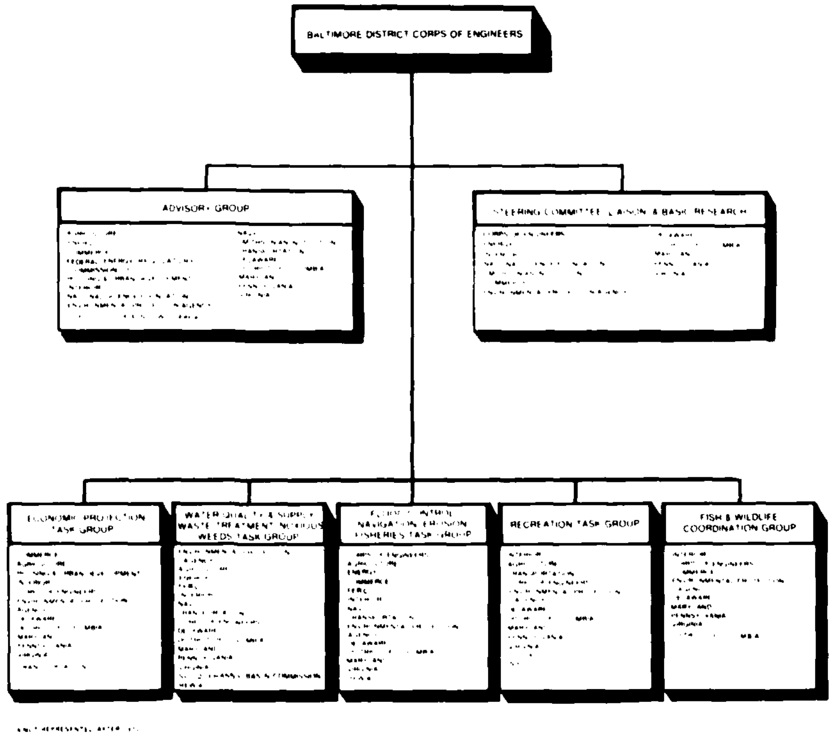


Figure I-4 Chesapeake Bay Study Organization

mechanism for the study. Since its establishment, the Advisory Group advised the District Engineer on study policy and provided general direction under which all study participants operated.

The Steering Committee for Liaison and Basic Research was charged with reviewing the work of the other study task groups in order to bring to their attention and to the attention of the District Engineer any pertinent technological advances in water resources development or the environmental sciences that may not be explicit in the task assigned to these groups. The five task groups were each concerned with the related resource categories and functioned as basic work groups. The members of the above described committees and groups actively participated in the problem identification and the plan formulation process and their views and findings contributed in no small measure to the quality of the study.

Since the beginning of the study, the general public has been kept informed of study progress. Their comments concerning the study have been requested, and positive action has been taken whenever appropriate. Direct and functional two-way communication has been established with interested conservation, industry, and political action groups.

Under this strategy, the public was continually informed of study progress. Channels of communication were de-

veloped to obtain information from the public, including input concerning the setting of goals and the formulation of the study. This information was incorporated into the study program by the Corps.

The public involvement elements that were implemented included: public meetings, publications, a documentary film, slide presentations, coordination with citizens' advisory group, mass media liaison, use of study-related exhibits, hydraulic model tours, and participation in special events.

Chesapeake Bay Hydraulic Model

The data on the physical dynamics of the Bay that were provided by the Chesapeake Bay Hydraulic Model were an important element of the Chesapeake Bay Study. The model is located at Matapeake, Maryland, on a 60 acre tract of land donated by the State of Maryland. The site is on the Delmarva Peninsula, lies along Maryland Route 8, and is approximately 3 miles south of the eastern terminus of the William Preston Lane Memorial Bridge (Chesapeake Bay Bridge). It is within commuting distance of over 3,000,000 people being less than 50 miles from Washington, D.C. and Baltimore, Maryland.

The hydraulic model of Chesapeake Bay is the largest estuarine model in the world. It is a fixed bed, geometrically distorted scale model hand molded in concrete; is 8 acres in area; and encompasses the Bay proper, all of its tributaries up to the head of tidal effects, and the adjacent overbank areas to the contour of 20 feet above mean sea level (See Figure I-5). The model is enclosed in a 14 acre prefabricated steel truss building in order to protect it from such elements as wind, rain, and debris.

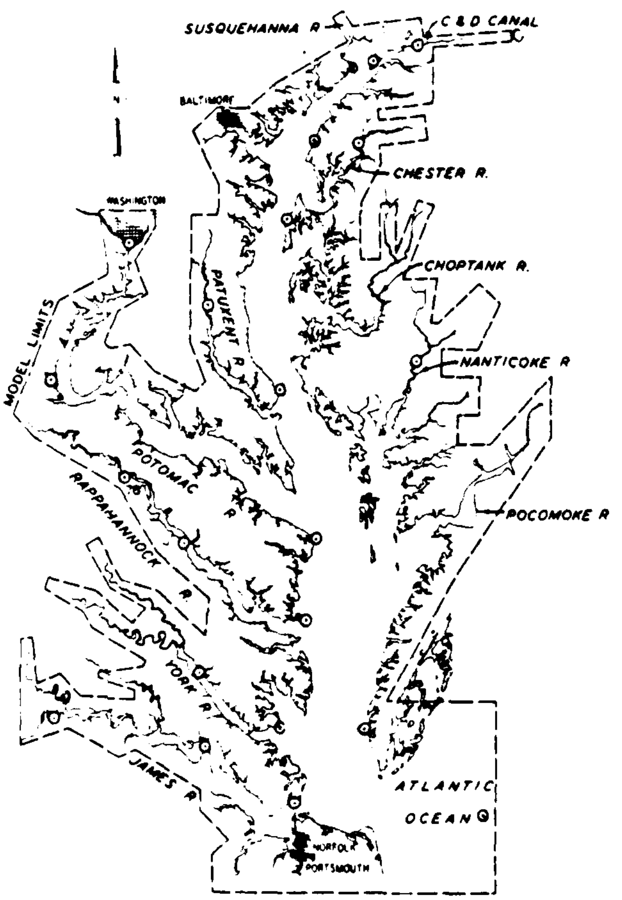


Figure I-5 Chesapeake Bay Model Limits

Chesapeake Bay conforms to the typical form of coastal plain estuaries. These are generally broad shallow water bodies. The average depth lies between 25 and 28 feet; and if the model were to be constructed to a reasonable natural scale, water depths would be generally extremely shallow. Because of this, the water would be too shallow to make meaningful measurements, and the effects of water surface tension would disturb model results.

To overcome these problems, the Chesapeake Bay Model, like almost all estuary models, is geometrically distorted. This means that it is constructed disproportionately by using larger scales for vertical dimensions than for horizontal dimensions. The degree of distortion, as well as the actual scales selected, is dependent on many factors including the size of the area that must be reproduced and the problems to be investigated. The Chesapeake Bay Model is constructed with scales of 1 to 1,000 *horizontally* and 1 to 100 *vertically*. This combination of scales is referred to as a distortion ratio of 10. This particular scale ratio has been found, over many years of experience, to provide the most economically sized model that will accurately reproduce the vertical and lateral distributions of current velocity, salinity, and tidal elevation.

The model's geometric scales also determine the time, volumetric, and velocity scales. The time scale is 1 to 100 which permits a semi-diurnal tidal cycle of 12 hours and 25 minutes to be reproduced in 7.45 minutes and a year of record in nature to be simulated in 3.65 days. The velocity scale is 1 to 10, the discharge scale 1 to 1,000,000 and the salinity scale is 1 to 1.

The total wetted area of the model at mean low water is almost 166,000 square feet and at mean high water about 184,000 square feet. The volume of water needed to fill the model to mean low water is about 450,000 gallons, and the amount of additional water required for the spring tide is about 36,000 gallons.

There are six basic measurements that are made on estuarine hydraulic models. These include water surface elevation, salinity, current velocity, dye concentration from dye dispersion tests, temperature, and sediment distribution. These measurements can effectively describe the physical impact on an estuarine resource of many of the works of man. Often, biological stress can be predicted from the knowledge of changing physical parameters.

Once construction of a model is completed, its operating similarity to an estuary's hydraulic and salinity phenomena must be verified. In order to accomplish this for the Chesapeake Bay Model, an extensive prototype data collection program was initiated. This involved the collection of data concerning tidal elevations, current velocities, and salinities at various points throughout the Bay system. Tidal elevation data were collected at 72 locations for at least one year's duration by the National Ocean Survey. That agency also conducted a 1,000 mile first order survey to establish a common reference datum for the tidal stations. Current velocity and salinity data were acquired at over 700 different stations for periods ranging from 3 to 5 days. This work was accomplished under contracts with The Johns Hopkins University, the University of Maryland, and the Virginia Institute of Marine Science.

The construction of the model was completed in May 1976 at which time calibration, or "fine-tuning," of it was initiated. Calibration and verification were completed in May 1978 and the initial model test (the Baltimore Harbor Channel Enlargement Study) was started in July 1978. The Waterways Experiment Station was responsible for the construction, verification, operation, and maintenance of the Chesapeake Bay Model.

Prior Reports

The following reports have been prepared under the auspices of the Congressional Authority for the Chesapeake Bay Study:

Report	*Copies Available From*
Chesapeake Bay Existing Conditions Report	NTIS[1]
Chesapeake Bay Existing Conditions Report	NTIS
Impact of Tropical Storm Agnes	Not Available
Chesapeake Bay Low Freshwater Inflow Biota Assessment	NTIS
Reports on Hydraulic Model Testing:	WES[2]
Verification of the Chesapeake Bay Model	
Baltimore Harbor and Channels Deepening Study	
Low Freshwater Inflow Study	
Nanticoke River, Maryland Dye Dispersion Study	
Norfolk Harbor and Channels Deepening Study	

Chesapeake Bay Existing Conditions Report

The *Chesapeake Bay Existing Conditions Report* was completed in 1973. This 7 volume report was the first one ever to be published that presented a comprehensive survey of the Chesapeake Bay Region and treated Chesapeake Bay as a single entity. The report contains an inventory of the hydrodynamic and biological processes of Chesapeake Bay, a description of the present uses of the Bay's water and related land resources, and an identification of existing problems and conflicts.

Chesapeake Bay Future Conditions Report

The *Chesapeake Bay Future Conditions Report* consists of a summary and 16 supporting appendices. It focuses primarily on the present and future uses of the Bay's water and related land resources as well as existing and future problems and conflicts. The publication of that report represented the completion of the first iteration of the problem identification phase of the Chesapeake Bay Study and set the stage for more detailed investigations and problem solving. A summary of the findings of the *Future Conditions Report* can be found in *Supplement A, Problem Identification.*

Impacts of Tropical Storm Agnes

Tropical Storm Agnes was one of the more devastating storms the Chesapeake Bay Basin has ever witnessed. Shortly after this storm had passed, Congress included in the Supplemental Appropriations Act of 1973, $275,000 to do a study oriented to assessing the damage caused by the storm and to determine the potential long term affects of it. The report on Tropical Storm Agnes was published in October 1975. The findings of this report are summarized in *Supplement A, Problem Identification.*

Chesapeake Bay Low Freshwater Inflow Study Biota Assessment

The purpose of this two phased report was to develop a methodology for determining how changes in salinity caused by decreased amounts of freshwater inflow affect aquatic organisms. It was prepared for the Corps of Engineers in May 1982 by Western Eco-Systems Technology, Incorporated (WESTECH) and was designed to be input to the Chesapeake Bay Low Freshwater Inflow Study. In this biota report, each of four sets of low freshwater inflow conditions were investigated. Changes in potential habitat for more than 57 biological organisms were predicted and mapped based on salinity and other variables. Changes in habitat, were found to either increase or decrease depending on the species, its life cycle, tolerances, and interactions with other organisms. Most habitats decreased as salinity increased. The findings of the Low Freshwater Inflow Biota Assessment Report will be discussed in detail in other sections of this report.

Reports on Hydraulic Model Testing

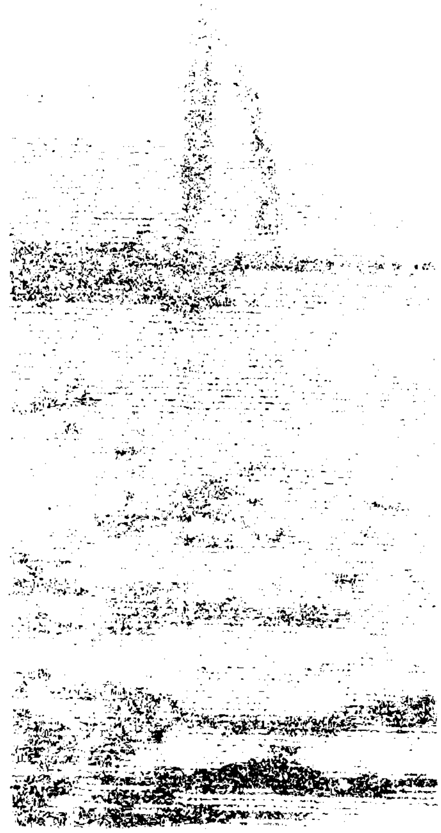
A report was prepared by the Waterways Experiment Station for each major test performed on the Chesapeake Bay Hydraulic Model. Each of these reports is described in further detail in *Supplement C to the Summary Report Hydraulic Model.*

Studies of Others

Chesapeake Bay is one of the most intensively investigated estuarine systems in the United States. Literally thousands of water resource related studies and research reports dealing with Chesapeake Bay have been published in this century. Many efforts have been undertaken in recent years to prepare comprehensive bibliographies of the reports dealing with Chesapeake Bay. The most recent and perhaps the most important of these bibliographies was published in 1976 as part of the Coastal Zone Management Programs of the

Maryland Department of Natural Resources and the Virginia Institute of Marine Science.

Published in four volumes, this bibliography was undertaken to document existing sources of information, to help identify research and data gathering needs, and to develop a comprehensive research and information services program for individuals interested in Chesapeake Bay. This bibliography includes citations for approximately 7400 prior reports dealing with Chesapeake Bay and its resources.



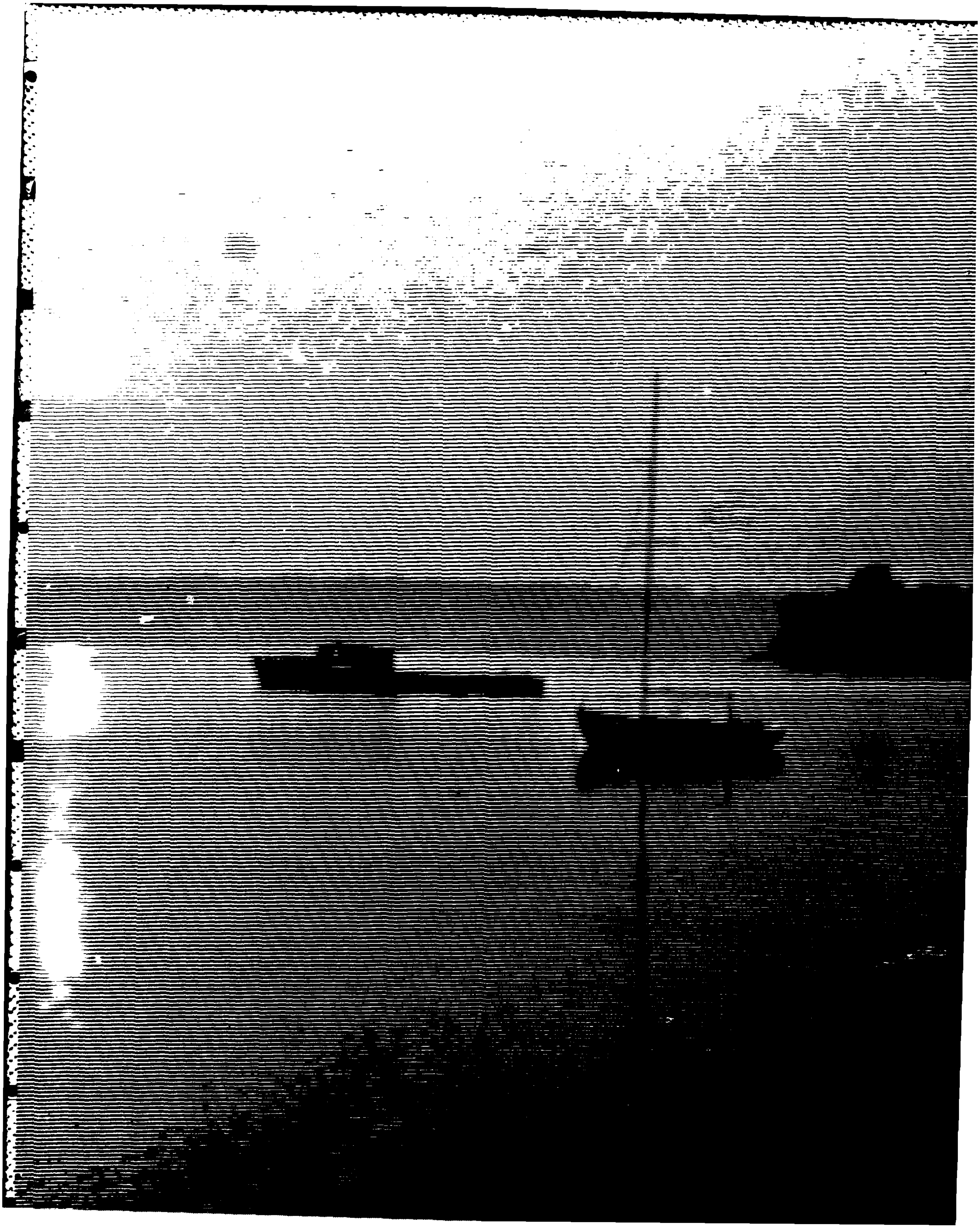
In September 1983, the Environmental Protection Agency published a report on the findings of its six year, $27,000,000 Chesapeake Bay Program. The report focused on three problem areas—toxic materials, nutrient enrichment, and the reduction of submerged aquatic vegetation. Included among the recommendations were a monitoring and research program, Bay wide nutrient strategies, and measures for eliminating the toxic materials problem.

In addition to the above mentioned reports, there are numerous other on-going or more recently completed studies and reports. The more important of these are:

*Study/Program**	*Sponsoring Agency*
Metropolitan Washington Area Water Supply Study	Corp of Engineers
Potomac Estuary Study	U.S. Geological Survey
Effects of Metals from Sewage Treatment Plants on the Chesapeake Bay	National Science Foundation
Natural Areas of the Chesapeake Bay Region	Smithsonian Institution
Delmarva Study	Soil Conservation Service
Maryland Coastal Zone Management Program	State of Maryland
Maryland Power Plant Siting Program	State of Maryland
Water Quality Management Program	State of Maryland
Upper Bay Survey	State of Maryland
Chesapeake Bay Wasteload Allocation Study	State of Maryland
Virginia Coastal Zone Management Program	Commonwealth of Virginia
Water Quality Management Program	Commonwealth of Virginia

*Studies listed are either on-going or completed in the last ten years.

NTIS--National Technical Information Service
WES- Waterways Experiment Station, Corps of Engineers



CHAPTER II

The Planning Setting

The 64,160 square mile Chesapeake Bay drainage basin is shown on Figure II-1. It extends from southern New York to Northern Virginia and includes portions of the States of New York, Pennsylvania, Maryland, Virginia, West Virginia and Delaware. There are over 50 rivers with widely varying geochemical and hydrologic characteristics contributing freshwater to Chesapeake Bay. The largest river on the east coast of the United States, the Susquehanna, drains nearly 43 percent of the basin and contributes an average of 51 percent of the freshwater inflow. The York, Rappahannock and James River system drains nearly 25 percent of the basin and contributes about 21 percent of the freshwater inflow. The Potomac, draining 22 percent of the basin, provides 18 percent of the total freshwater inflow. The Patuxent is the smallest of the major rivers draining only a little over one percent of the basin and contributing only 1.5 percent of the freshwater inflow.

The Upper Western Shore and Eastern Shore basins are composed of many streams and rivers; all of which have small discharges of freshwater. The larger rivers on the Upper Western Shore include the Severn, Magothy, Patapsco, Middle, Back, Gunpowder and Bush Rivers. The flat, low discharge streams of the Eastern Shore include the Chester, Wye, Tred Avon, Choptank, Nanticoke and Pocomoke Rivers.

Geology

The Chesapeake Bay drainage basin is made up of five physiographic provinces. These are the Coastal Plain, Piedmont Plateau, Blue Ridge Province, Valley and Ridge Province, and the Appalachian Plateau. All of these provinces parallel the Atlantic Coast in belts of varying width that extend from New England to the Gulf of Mexico. Their locations are shown on Figure II-2.

Included in the Coastal Plain Province are the Eastern Shore of Maryland and Virginia, most of Delaware and a small portion of the Western Shore. On the Eastern Shore and in those portions of the Western Shore adjacent to the Bay, the coastal plain is largely low, featureless, and frequently marshy, with many islands and shoals that sometimes extend far off shore. The province is a

Table II-1

Basin Characteristics

Sub Basin	*Drainage Area (mi.²)*	*Percent Total Basin*	*Average Freshwater Inflow (CFS)*	*Percent Total Inflow*
Susquehanna	27,510	43	39,240	51
Potomac	14,217	22	13,770	18
Rappahannock	2,885	5	2,940	4
York	2,857	4	2,660	3
James	10,187	16	10,940	14
Patuxent	875	1.5	884	1.5
Eastern Shore	4,061	6	4,697	6
Upper Western Shore	1,568	2.5	1,758	2.5

gently rolling upland in the inland portion of the Western Shore and in the northern portion of the Eastern Shore. The coastal plain reaches its highest elevation in areas along its western margins.

The coastal plain is composed primarily of unconsolidated, southeasterly dipping, sedimentary layers of sand, clay, marl, gravel and diatomaceous earth that rest on a base of hard crystalline rock. These layers, which can be readily seen in areas where wells have been drilled, increase in thickness towards the continental shelf. The basement rock is exposed in the form of ridges in a few isolated areas where water has cut deep channels.

The Piedmont Plateau is not, as its name implies, a plateau. It is an area of low hills and ridges which tend to rise above the general lay of the land. Its maximum elevations are near the Appalachian Province on the west. Many of the stream valleys are quite narrow and steepsided. These were cut into the hard crystalline rocks by the rivers and streams.

The parent materials of the Piedmont Plateau Province are both older and more complicated than those of the coastal plain. Structurally complex crystalline rocks have been severely folded and subjected to great heat and pressure, thereby creating metamorphic rocks.

The Blue Ridge Province consists of a narrow band of mountains between the Piedmont Plateau and the Valley and Ridge Province. These mountains extend from southern Pennsylvania to northern Georgia. One of the most prominent of them is South Mountain in Pennsylvania. Marked topographic differences separate the Blue Ridge from the Great Valley section of the Valley and Ridge Province on the northwest and the much lower Piedmont Province on the southeast. It rises to an elevation of 2,000 feet in South Mountain. The province is made up of rocks that overlay sedimentary rocks, chiefly sandstones, and shales of cambrian age. These have been partly altered to form quartizite and phyllite.

The Valley and Ridge Province is a folded thrust faulted province of parallel or nearly parallel ridges and valleys. The topography was formed by anticlines, synclines and thrust sheets of

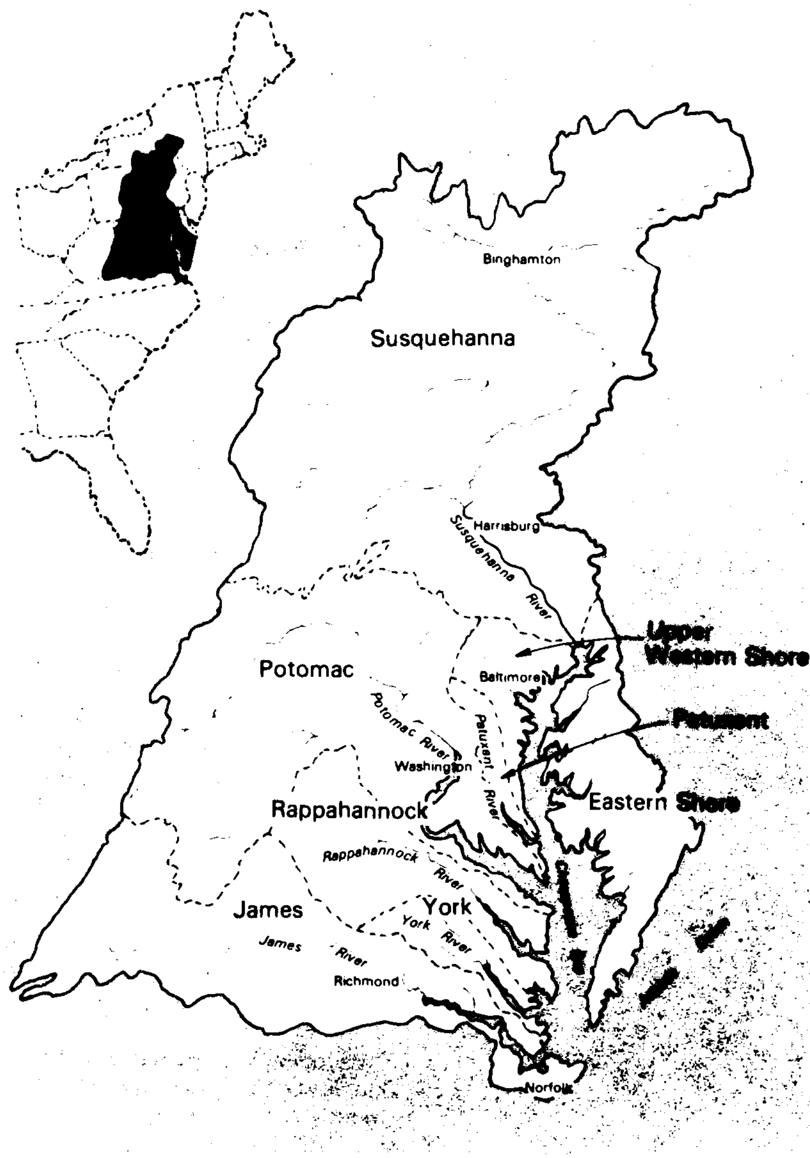


Figure II-1 Chesapeake Bay Drainage Basin

strata of paleozoic age. The rectangular drainage of the province contrasts sharply with the tree-like drainage system of the Piedmont Pla[illegible]u.

The Valley and Ridge Province is underlain by a sequence of alternating conglomerates, sandstones, shale, limestone, and coal. The conglomerates and sandstones are the "ridge markers". Less resistant limestone and shale underly the valleys of the region. The resistance of the rock to erosion varies greatly and has a very important effect upon the topography. The broad low lands composing the valley are due to the weaknesses of the cambro-ordovician limestones and shales. The ridges of the Valley and Ridge belt are composed of very resistant middle and upper paleozoic sandstones and conglomerates, particularly the Tuscarora Sandstones, Oriskany-Group, Pokono Formation, and Potsville Formation.

The Appalachian Plateau forms the western division of the Appalachian Highland. The plateau extends eastward to the Catskill region and southward to Alabama. Its eastward face is usually a pronounced erosional escarpment called the Allegheny Front. Its westward boundary merges gradually into the great plains of the Mississippi Valley.

The plateau is underlained by sedimentary rocks deposited during the Paleozoic Era. Included are conglomerates, sandstones, shales, limestones, and bituminous coal. The rocks are nearly

Pacific northwest, and southern portion from the Gulf Coast are the principle source of precipitation. Coastal storms, or "northeasters" also contribute abundances of rain as do the occasional hurricanes and tropical storms that move up the Atlantic seaboard. Violent thunderstorms bring heavy local rain and often hail.

Snowfall within the region is chiefly a function of the latitude and altitude of a particular location. Average annual snowfall ranges from less than 10 inches in southeastern Virginia to over 50 inches in the northern part of the Susquehanna River Basin.

Most of the Chesapeake Bay Basin is under the year-round influence of the prevailing westerly winds. These are strongly modified by topography. Brief windstorms with gale force wind gusts are experienced in the fall, winter, and early spring. Major storms of tropical or extra-tropical origin periodically strike the basin with violent winds. Tornados are not common and have caused only limited damage.

The average annual temperature in the Chesapeake Bay basin varies from about 45 °F in the northern part of the Susquehanna River Basin to 61 °F in Virginia. There is a marked difference in summer and winter temperatures. Summers are hot and humid, especially near the coast. Northern winters are fairly long and severe with growing seasons averaging less than 100 frost-free days in some areas. The growing season in the southern portion averages nearly 200 days.

Figure II-2 Geological Provinces

horizontal in New York dipping slightly to the south. The strata of the plateau province lie nearly horizontal in most places. Gentle folding is present over a broad region. The orientation of the long axes of the folds is northeasterly, and because of the subsequent development of streams, the topographic features trend in the same direction. The general drainage pattern is dendritic. This has been modified slightly by glaciation and the structural attitudes of the rock strata.

Climate

There is a wide range of climatic conditions in the Chesapeake Bay Basin. Generally, the climate of the coastal low lands is tempered by its proximity to the ocean. There are therefore less extremes in temperature and precipitation than there are in the western-mountainous area. Three general types of weather patterns influence the region. These are: cold, dry air flowing down from the Arctic; warm, moist air from the Gulf States; and cold, moist air moving in from the ocean.

Average annual precipitation in the Chesapeake Bay Basin varies from about 30 inches to 52 inches. Generally, there is more rainfall in the southern portion of the basin than there is in the north. The distribution of the precipitation is relatively uniform throughout the year. Spring is the wettest season while summer is often the dryest.

Low pressure cyclonic systems crossing the northern part of the basin from the

The Chesapeake Bay Estuary

The Chesapeake Bay is a mere youngster, geologically speaking. It is generally believed that the Bay was formed about 10,000 years ago, at the end of the last ice age when the great glaciers melted and poured uncounted billions of gallons of water back into the world's oceans. The ocean level rose several hundred feet and inundated large stretches of coastal rivers. The ancient Susquehanna, which drained directly into the Atlantic Ocean near what is now the mouth of the Bay, was one of these drowned waterways.

This newly formed body of water was later to be named Chesapeake Bay. Chesapeake Bay is about 200 miles long

and varies in width from 4 to 30 miles. Although the Chesapeake is the largest estuary in the United States, with a surface area of approximately 4,400 square miles, the average depth of it is only about 28 feet. About two thirds of the Bay is 18 feet deep or less. This reflects the fact that the area around the Old Susquehanna is characterized by relatively low relief. There are, however, deep holes which generally occur as long narrow troughs. These troughs are thought to be remnants of the ancient Susquehanna River Valley. The deepest of these holes is about 175 feet and is located near the southern tip of Kent Island.

Chesapeake Bay is a complex dynamic system. The terms "restless", "unstable" and "unpredictable", which generally describe the young of most animal species can also be used to describe this young estuary. The ebb and flow of the tide and the incessant actions of the waves are the most readily perceptible water movements in the Bay. Average maximum tidal currents range from 0.5 knots to over 2 knots. The mean tidal range in Chesapeake Bay is small, generally between 1 and 2 feet. Except during periods of unusually high winds, waves in the Bay are relatively small, generally less than 3 feet in height.

The most important feature that distinguishes an estuary from a river or ocean is the temporal and geographic variations in salinity levels. In the Chesapeake, salinities range from about 33 parts per thousand at its outlet to the ocean to near zero at the head of the Bay and its estuarine tributaries. This variation in salinity is directly related to the quantity of freshwater inflow to the Bay from its tributaries. As the quantity of freshwater inflow increases, the salinities of the Chesapeake tend to decrease and conversely, as inflow decreases, salinity increases. This is illustrated in Figure II-5. In the spring freshwater inflows are high and consequently salinities are low. In the fall the opposite is normally true.

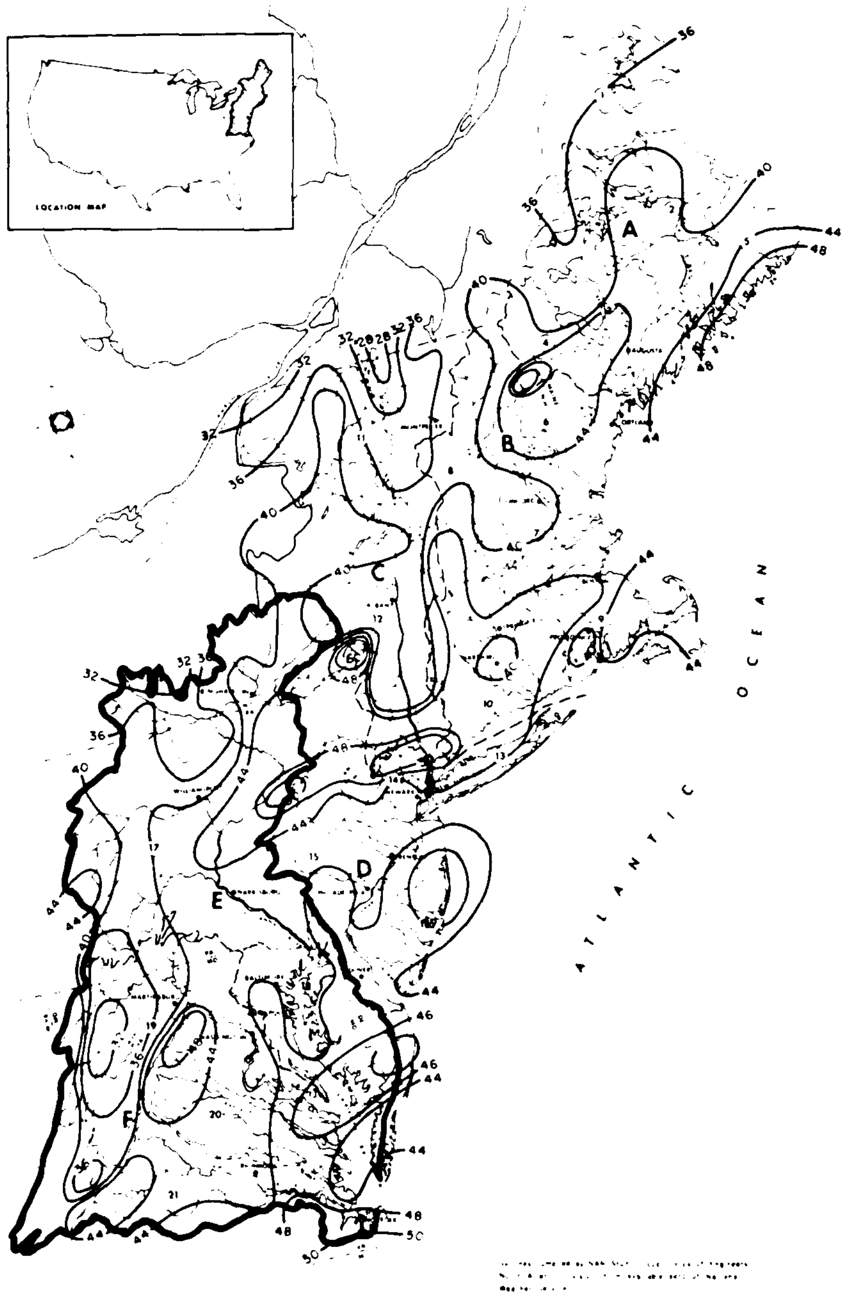


Figure II-3 Average Annual Precipitation

The presence of salinity in the estuary results in the formation of non-tidal current patterns. As can be seen in Figure II-6, there is often a two-layered flow pattern in the Bay and its major tributaries. The heavy seawater tends to flow up the estuary in the deep layers and the lighter freshwater tends to flow seaward in the upper layers. Therefore, Chesapeake Bay is not only more salty at its mouth than at its head, but is more salty near the bottom than at its surface. Also, higher salinities are generally found on the Eastern Shore than on a comparable area of the Western Shore. This is due to the greater river inflow on the Western Shore and to the earth's rotation.

Because of the seasonal variations in salinity and the natural density differences between fresh and saline water, significant non-tidal circulation often occurs within the Bay's small tributary embayments. In the spring, during the period of high freshwater inflow, salinity in the embayments may be greater than in the Bay. Because of this salinity difference, surface water from the Bay

flows into the tributaries on the surface while the heavier more saline bottom water from the tributaries flows into the Bay. As Bay salinity becomes greater through the summer and early fall, Bay waters flow into the bottom of the tributaries, while tributary surface waters flow into the Bay.

Salinity is one of the more important factors controlling not only the types of aquatic life in Chesapeake Bay, but the geographical area in which they are located. For instance, marine species live near the ocean; freshwater species near the head of the Bay. Estuarine unique species live near the middle of the Bay. Most of these organisms can adjust to small changes in salinity in any given season and the wide variation in seasonal salinities. However, sudden changes in salinity or extreme changes caused by drought or man-made events may upset the equilibrium between the organisms and their environment.

But, salinity is not the only parameter that determines the distribution and abundance of organisms in Chesapeake Bay. Equally important are dissolved oxygen levels, temperature, light, nutrients, sediments and the distribution detrital materials. The amount of these present in any given location is related to the complex physical dynamics of the estuary; i.e., freshwater inflows from the tributary river, tidal and non-tidal induced current patterns, and wave action. For instance, the freshwater inflow from the Chesapeake Bay's tributaries carries to the estuary sediments, nutrients, and other dissolved and suspended materials. In addition, the temperature of the Bay is somewhat influenced by these freshwater inflows.

Both the tidal and non-tidal induced current patterns, as well as wave action, provide for the mixing, transportation, and distribution of organic and non-organic materials. The non-tidal currents are especially important in the transport of larvae, suspended sediments, spores, gametes and other non-motile organisms. They also play a role in bringing food and oxygen to bottom organisms.

Tides and waves are also important to the intertidal zone (the shoreline area between high and low tides) of an estuary because of their wetting action. This action is beneficial to many plant and animal species. In sheltered waters, the mixing of water by tides and wave actions is important for the prevention of excessively high temperatures and salinity stratification which could be harmful to some of the aquatic species. The turbulence caused by wave action also plays a role in the aeration of the waters to provide sufficient oxygen for biotic respiration.

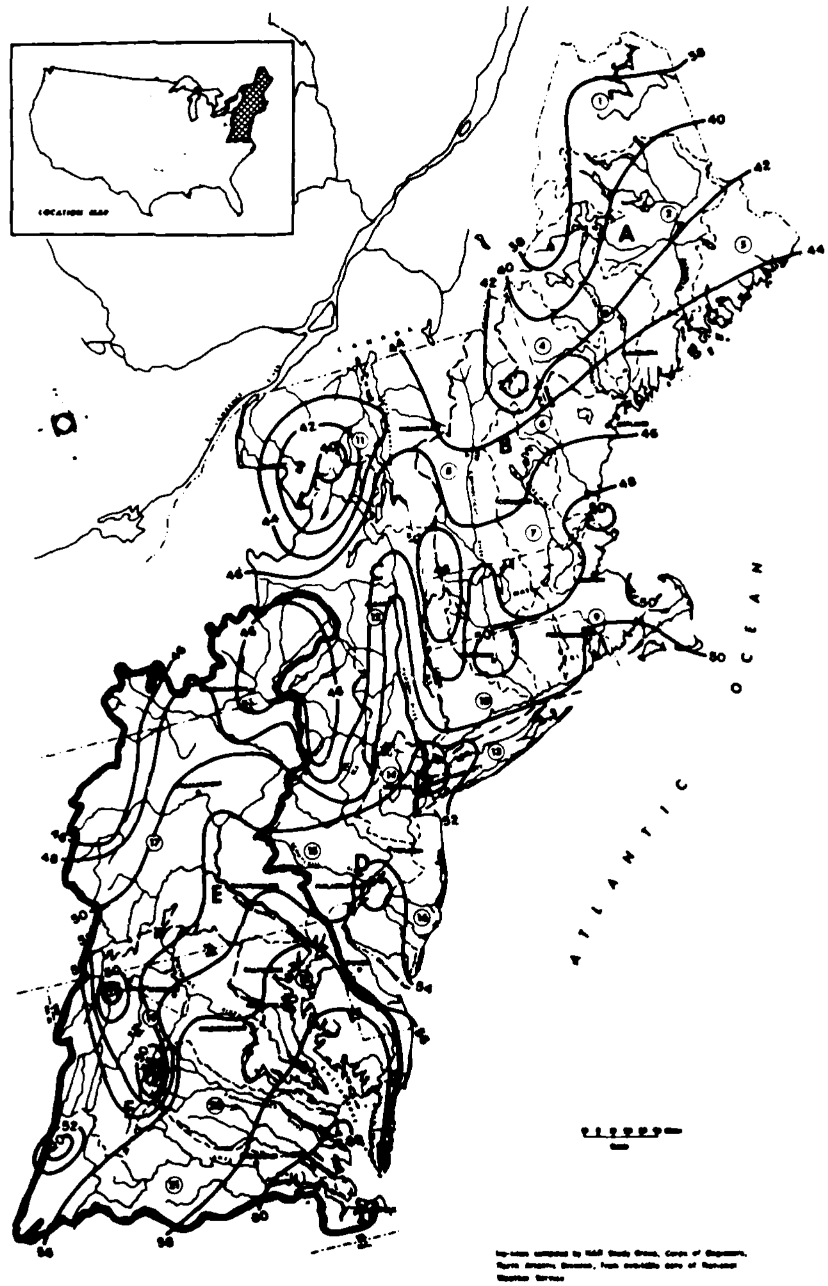


Figure II-4 Average Annual Temperature

Aquatic species vary in the level of dissolved oxygen they need for health. Sometimes they can function in waters with dissolved oxygen levels as low as 1.0 to 2.0 milligrams per liter. But, dissolved oxygen levels of about 5.0 milligrams per liter are generally considered necessary, to maintain a healthy environment over the long term.

Dissolved oxygen levels vary considerably both seasonally and according to depth. During the winter, the Bay is high in dissolved oxygen since it is more soluble in cold water than in warm. With the spring and summer high water temperatures, the dissolved oxygen content decreases. While warmer surface waters stay near saturation, the dissolved oxygen in the deeper waters becomes significantly less despite the colder temperatures at the bottom. This is due to the increasing oxygen demand by bottom dwelling organisms and decaying organic material. Also, decreased vertical mixing influences this process. Through the summer, the waters below 30 feet may become oxygen deficient. By early fall, as the surface waters cool and sink, vertical mixing takes place and the oxygen content at all depths increases until there is an almost uniform distribution.

The effects of temperature on the estuarine system are also extremely important. Since the waters of the Chesapeake Bay are relatively shallow compared to the ocean, they are particularly sensitive to atmospheric temperature conditions. Generally speaking the annual temperature range in the Chesapeake Bay is between 0° and 29°C. Because the mouth of the estuary is close to the sea, it has relatively stable temperatures as compared with the upper reaches. Conversely, the upper reaches are more affected by freshwater inflows than are the lower ones and have a wider range of temperatures.

Some heat is required by all organisms for the functioning of body processes. These processes are restricted, however, to a particular temperature range. Temperatures above or below the critical range for a particular species can be fatal unless the organism is able to move out of the area. As discussed earlier, temperature also causes variations in water density which plays a role in salinity stratification and non-tidal circulation.

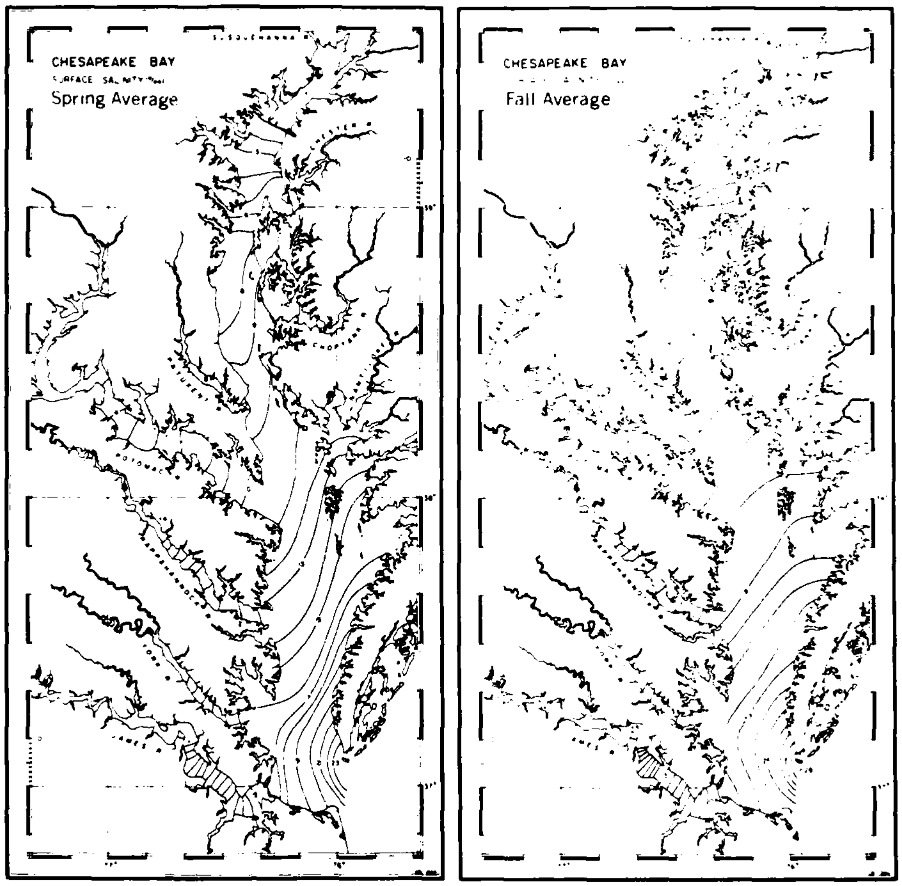


Figure II-5 Geological and Seasonal Variations in Salinities in Chesapeake Bay

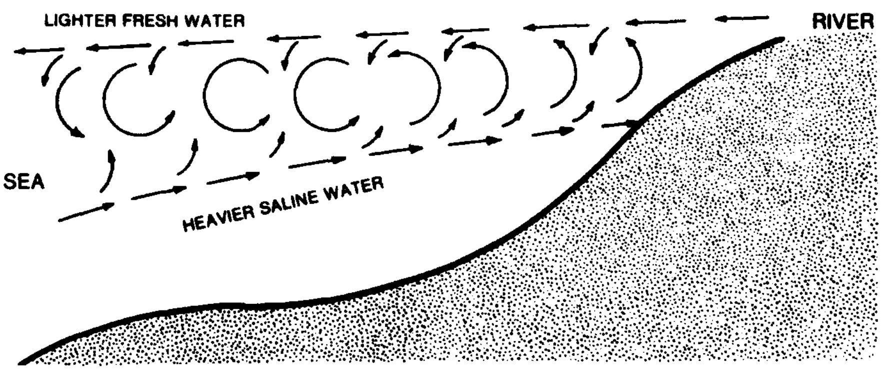


Figure II-6 Circulation in a Partially Mixed Estuary

Light is necessary for the survival of plants because of its role in photosynthesis. Turbidity, more than any other physical factor, determines the depth light will penetrate in an estuary. Turbidity results from the suspended material (mineral and/or organic in origin), which is transported through the estuary by wave action, tidal currents, and non-tidal currents. While the absence of light may be beneficial to some bottom dwelling organisms, plant life must be exposed to light for the photosynthetic process to take place. Reduction of plant life (especially plankton and SAVs in the open estuary) will reduce benthic (bottom dwelling) and zooplankton populations which in turn will reduce fish productivity.

Nutrients are essential to the normal functioning of an organism. In Chesapeake Bay, important nutrients include nitrogen, phosphorus, carbon, iron, manganese, silicon and potassium. It is generally believed that most of the nutrients required by estuarine organisms are present in sufficient quantity in Chesapeake Bay. Excesses of some nutrients are often an important problem.

Too much nitrogen and phosphorus, for example, can result in the injury to or elimination of desirable species as well as the growth of noxious algae. Relatively little is known about the quantities of specific nutrients necessary for the healthy functioning of individual species or biologic communities. More importantly, there is limited knowledge about the nutrient budget, i.e., the input, output, and distribution of nutrients in the Chesapeake Bay system.

There is no question that Chesapeake Bay is a complex estuarine system that is difficult if not impossible to fully understand. The existence of a single organism is the result of the interplay of many physical, biological, and chemical factors. As a simple example, the levels of both salinity and temperature will affect the metabolism of an aquatic organism. In addition, both salinity and temperature can cause a drop in the oxygen concentration in the water and thus adversely affect the organism. While the effects of these variables individually may be of a non-critical nature, the combined effects of the three stresses may be severe to the point of causing death. These three parameters in turn also interact with other physical and chemical variables such as current patterns, pH, carbon dioxide levels, the availability of nutrients, and numerous others. The subtle variable of time may also become critical in many cases. The important point is that the physical and chemical environment provided by Chesapeake Bay to the indigenous biota is extremely complex and difficult, if not impossible, to completely understand.

The Biota of Chesapeake Bay

The extraordinary extensiveness and diversity of Chesapeake Bay stand it apart as one of the more productive of the world's estuaries. The Bay and its adjacent wetlands and fastlands provide a vast feeding, shelter and nursery grounds for nearly 2700 varieties of organisms ranging in complexity from bacteria, fungi, phytoplankton, and microalgae to the more familiar fish, reptiles, birds and mammals.

Chesapeake Bay is one of nature's more demanding environments. Its constantly changing physical and chemical makeup limit the types of organism living there to those that are able to readily adapt to new surroundings or to move to areas more hospitable to them. On the other hand, the relatively few types of species which do live in Chesapeake Bay normally flourish.

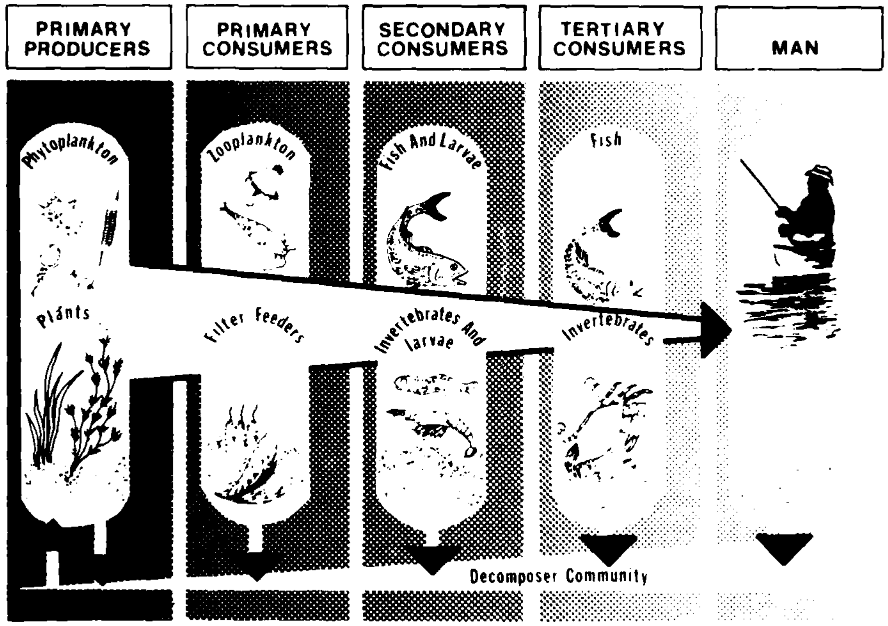


Figure II-7 The Bay Food Web

There are a number of reasons for this. First, each organism can find a place in the estuary where the salt levels are best suited to its needs. Second, the circulation patterns in the zone where lighter freshwater mixes with heavier sea water tend to create a "nutrient trap" which acts to retain and recirculate nutrients. Third, water movements in the estuary do a great deal of "work" removing wastes and transporting food and nutrients. This enables many organisms to maintain a productive existence in an environment that does not require the expenditure of a great deal of energy for food gathering and excretion. Fourth, the recycling and retention of nutrients by bottom dwelling organisms, the effects of deeply penetrating plant roots, and the constant formation of detrital material in the wetlands create a "self-enriching" system. And last, estuaries benefit from a diversity of plant types which together provide year round energy to the system. Chesapeake Bay has all three types of producers that power the ecosystems of our world: macrophytes (marsh and sea grasses), benthic microphytes (algae which live on or near the bottom), and phytoplankton (minute floating plants).

All of these processes are important in a complex network of interactions called the food chain. The food chain is the way in which energy is transferred through the ecosystem. There are basically four parts to it called trophic levels (five parts if human beings are included). The organisms that are indigenous to each of these groups are called primary producers, primary consumers, secondary consumers and tertiary consumers (predators). Plants are the primary producers that convert sunlight and nutrients into living tissue. The primary consumers are the grazers which feed upon the plants. The secondary consumers eat the primaries and in turn are eaten by the tertiary consumers. Some organisms function at several levels. The canvasback duck eats both plants and a small clam. Humans eat oysters (primary consumer), anchovies (secondary consumer) and striped bass (tertiary consumer).

Aquatic Plants

As implied above, certain aquatic plants are critical to the health and productivity of Chesapeake Bay. Plants use sunlight and the inorganic nutrients in the water to produce plant tissue — the energy source that drives the estuarine ecosystem. Thus, these plants, ranging from microscopic algae to the larger rooted aquatics, are the primary producers — the first link in the aquatic food chain. Aquatic plants exist in the natural environment in a myriad of shapes, forms, and degrees of specialization. They are found in waters of widely varying physical and chemical quality.

Phytoplankton. Phytoplankton is a general term for free floating microscopic plants that live in both fresh and saline waters. They are moved about by currents and tides in a manner not completely understood. The more important of the phytoplankton are the green algae, diatoms and dinoflagellates. There are relatively few different types of phytoplankton. On the other hand, when they do occur, they are present in tremendous numbers.

Salinity often controls the types of phytoplankton present in a given area, i.e., a given type of species lives in areas where the salt levels best suits its needs. The phytoplankton have therefore been grouped into the following classifications or associations.

Type	Salinity Tolerance
Tidal Freshwater Phytoplankton	0 to 5 ppt
Oligohaline/Low Mesohaline Phytoplankton	3 to 10 ppt
Mesohaline Phytoplankton	8 to 15 ppt
Polyhaline Phytoplankton	13 ppt to seawater

Phytoplankton perform a vital function in the Chesapeake Bay ecosystem. They are the major primary producers in most of the Bay's tidal waters providing organic material to the food web and ultimately sustaining the fisheries. Many organisms depend on phytoplankton for part or all of their food supply. Algae is eaten by the copepods. Larger species of phytoplankton are eaten by zooplankton and juvenile fish. Animals living near the bottom graze on phytoplankton and filter feeders such as the oyster eat the smaller species.

Not all phytoplankton are equally good as food and some (such as toxic dinoflagellates) are often detrimental. Under certain conditions, there is an almost "explosive" growth of these organisms. This is called a "bloom". These blooms usually occur in later summer or early fall. The result is a distinctive green color to the water. In addition to being a nuisance, they cause ecological damage by decreasing the amount of dissolved oxygen.

Submerged Aquatic Vegetation. Submerged aquatic vegetation are plants (usually rooted) which live submerged below the water's surface. Submerged aquatic vegetation in Chesapeake Bay usually reproduce by seeds or rhizomal growth.

Like most of the organisms that live in Chesapeake Bay, the types of submerged aquatic vegetation present are directly related to salinity levels. They are, generally, classified into three groups, i.e., freshwater species, brackish water species (about 0.5 to 15 parts per thousand salinity) and marine species (greater than 15 parts per thousand salinity). These types of plants are important food and habitat for fish and wildlife of all types, and play a vital role in the recycling of nutrients from the deep sediments.

Emergent Aquatic Vegetation. As their name implies, emergent aquatic vegetation are plants whose stems extend above the water surface. They grow in areas that are either always underwater or occasionally underwater. These plants make up the bulk of the vegetation in the Chesapeake Bay wetlands; one of the great tidal wetland systems in the United States.

Wetlands are also classified according to salinity levels. There are three general types. These are, coastal freshwater, coastal brackish water, and brackish irregularly flooded wetlands. The coastal freshwater marshes are located in areas where the salt levels are very low. The coastal brackish water marsh is normally located in areas where the salinities range from 8 to 13 parts per thousand. These marshes are nearly always underwater. The brackish irregularly flooded marsh tolerates salinities from about 8 parts per thousand to that of seawater. They are located in areas that are only occasionally flooded.

There are many different types of plants that live in the freshwater wetlands. Both the coastal brackish marshes and the irregularly flooded marshes have fewer types of plants than freshwater marshes. Also, freshwater marshes are a more important food source for waterfowl and some other types of animals.

Wetlands are considered by many people to be one of the more important parts of the ecosystem. They help to control erosion and they provide a place to live for many of the organisms. Some animals feed directly on the live plants, while, others use the materials that have broken off (detritus) for their food. Fish use the marsh for spawning, as a nursery, and/or as a feeding area for the adults. Waterfowl and mammals such as muskrats and nutria use the leaves, stalks, rhizomes, and seeds of the vegetation for food. Muskrats and nutria live year around in the marshes. Migratory and resident waterfowl depend on the wetlands for cover and nesting habitat; as do some songbirds. Many birds, such as herons and egrets feed on the fish and other species which live in the marsh. Many estuarine organisms at the lower end of the food chain (for instance copepods) use the detritus and/or the micro-organisms it supports as a food source. These organisms, in turn, serve as food for other organisms.

Animals

The energy supplied to the ecosystem by the plants of the Bay must be made available in some manner to the meat eating predators, including human beings. This vital link is filled by the primary and secondary consumers. Included in these are many varieties of organisms such as zooplankton, worms, shellfish, crabs, finfish, birds, and waterfowl.

Zooplankton. Zooplankton are small crustaceans such as copepods, the larvae of most of the estuarine fin and shellfishes, several shrimp like species, and other animal forms that float with the currents and tides. Phytoplankton and plant detritus (along with adsorbed bacteria, fungi, protozoa, and microalgae) are consumed directly by the zooplankton and other larger aquatic species. Zooplankton are the most important primary consumers in Chesapeake Bay. Thus zooplankton are a key link in the transfer of phytoplankton plant material to species in the higher trophic levels. Zooplankton also regulate phytoplankton abundance and the availability of food for higher organisms.

Zooplankton, particularly copepods, are an important food source for larval and adult fish such as menhaden. High densities of certain copepods are critical to the survival and development of the larval of anadromous fish such as the striped bass.

Combjellies and jellyfish are an important part of the Bay's plankton community. They feed on other zooplankton, being particularly active during the summer months. While the primary food for these organisms is zooplankton, they also eat a certain amount of larger phytoplankton, detritus, and juvenile and small adult fish. The combjellies and jellyfish are also important to the cycling of nutrients such as phosphorous and nitrogen. Zooplankton fecal material enters the detritus/bacteria pathway and may in turn be used as food for other animals.

As with the other species of Chesapeake Bay, the type of zooplankton present in a given area is primarily related to salinity. In the upper Bay and upper reaches of its tributaries, freshwater varieties of zooplankton are present, while in the lower Bay, near the sea, the zooplankton are the type whose existence is dependent on high salinity levels.

Relatively little is known about the abundance of micro-zooplankton. It is believed, however, that they are extremely abundant, have rapid metabolic rates, and fast turnover rates. They probably contribute greatly to the energy flux of the ecosystem by feeding on the phytoplankton and in turn, serving as a food source for larval fish.

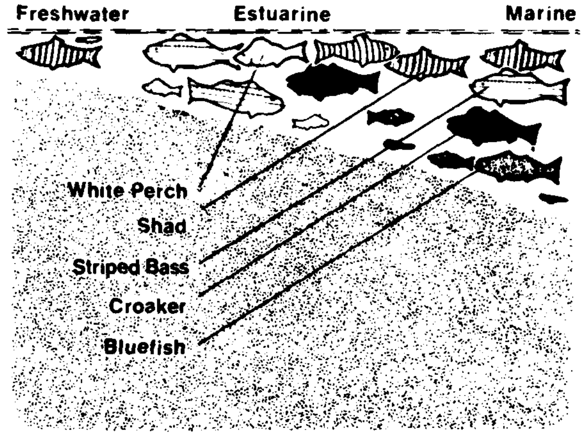


Figure II-8 Fishes: Their Use of the Estuary

Benthics. Organisms that live on or near the bottom of the Bay are called benthics. Most of these organisms are primary consumers, although some of them are secondary and tertiary consumers. Included among the benthics are oysters, clams, crabs, barnacles, sponges, worms, and many other types of aquatic animals. They are a major link in the transfer of energy through the ecosystem. They eat many of the primary producers and in turn, are often the basic food source for fish and other animals.

Benthics are normally classified according to where they live in relation to the bottom. Epifauna are those organisms which are attached to or just above the bottom (oysters), while the infauna are those species which burrow into the bottom (worms). Some of the species that are normally classified as benthics do not necessarily spend their entire lives near the bottom. For instance, although the crab is benthic oriented, it is capable of considerable swimming and can often be found near the surface. The sea nettle is a benthic organism only in its early life stages.

The types of benthics that live in any geographical area is normally determined by salt levels, the type of bottom sediments, and water depth. For instance, the oyster lives in relatively shallow, hard bottom areas where the salt levels are greater than 5 parts per thousand, while, one of the lethal diseases that attacks oysters (MSX) is active in areas where the salt levels are above 15 parts per thousand. Soft shell clams can thrive in low salinity areas, while barnacles and sponges live only in high salinity areas. Mysid shrimp and mud crabs live in areas where there are moderate salinities and brackish water clams live in low salinity areas. A few of the organisms, such as crabs, are not particularly sensitive to bottom type or salinity levels. These are widely distributed in the estuary.

Benthics are also important in nutrient recycling, sedimentation, and the oxygen cycle. Filter feeders, such as oysters and clams, pump large volumes of water through their bodies and take food from it. Deposit feeders, such as worms, plow through the sediments in search of food. Predators, such as blue crabs, scurry across the sediment surface. All these activities help to aerate the sediments, increasing the rate of diffusion of material into the water and facilitating the passage of oxygen into the sediments.

Benthic animals also affect the structure of the sediments. Some build tubes or burrows through which they pump water. Many benthic animals bind sediments together in fecal pellets. The sediments are therefore able to more readily settle to the bottom.

Fish. There are nearly 290 different types of fish that spend at least a portion of their lives in the Chesapeake. As with nearly every other organism that lives in the Chesapeake Bay, salinity is one of the more important factors in the types of species that are found in a given geographical area. There are four general groups of fish in the Chesa-

peake — freshwater species, estuarine species, marine species, and diadromous species.

The diadromous fish can be found at some stage of their lives in nearly any part of the estuary. Some of these fish are anadromous, i.e., they spawn in the rivers or the freshwater portions of the estuary. A large portion of their lives, however, is spent in either the more saline portions of the Bay or in the ocean. Typically, an anadromous fish is born in and spends its early life in the upper portions of the Bay. As it becomes an adult it migrates to the ocean. Later, it reenters the estuary to spawn in its headwaters or in one of the tributaries.

Estuarine fish are those which spend most of their lives in the saline portions of the estuary. There are only 24 of these type species which reside in the Chesapeake. Again, salinity is a factor in determining which of these species can be found in a geographical area.

Marine species are those that normally live in the ocean but periodically visit those portions of Chesapeake Bay where the salt levels are high. There are 174 of these in the Bay — 59 are regular summer visitors, 93 are sporadic summer visitors, 6 are regular winter visitors, and 16 are sporadic winter visitors.

There are 46 different types of freshwater fish in Chesapeake Bay. Fourteen of these live permanently in the Chesapeake, while 32 species stray into it from above the fall line or more rarely through the dismal swamp.

Another way of classifying the fish is by separating those which spend most of their lives in the Bay from those which are migratory. In its publication *Chesapeake Bay — Introduction to an Ecosystem*, the Environmental Protection Agency has addressed the fish from this prospective. Its description is as follows:

"Approximately 200 (sic) species of fish live in the Chesapeake. They can be divided into permanent residents and migratory fish. The residents tend to be smaller in size, therefore less capable of negotiating the distances often covered by the larger migratory species.

"Smaller resident species include killifishes, anchovies, silversides, hogchokers and gobies. They are normally found in shallow water where submerged vegetation provides cover. Here they feed on a variety of invertebrates such as zooplankton and amphipods.

"Larger residents also tend to make their home in these feeding areas, feeding on the invertebrates and the smaller resident fish.

"The migratory fish generally fall into two categories: those who spawn in the Bay or its tributaries, and those who spawn on the ocean shelf. The members of the Bay spawning category migrate varying distances to spawn in fresh water. This group includes a few species that really could be considered Bay resident. For instance, during the spawning season, yellow and white perch travel relatively short distances from their residence areas in the brackish water of the Bay to freshwater areas in the upper Chesapeake. Striped bass also spawn in the low salinity areas of the Bay. Some remain in the Chesapeake to feed, while others migrate to the ocean waters. Shad and herring are truly migratory, traveling from the ocean to freshwater to spawn and returning to the ocean to feed.

"Other migratory fish spawn on the ocean shelf and use the Bay strictly for feeding. Some journey into the Bay while still in the larval stage and use the shallow waters of the Bay as a nursery. Croakers, drum, menhaden, weakfish and spot fall into this group. The menhaden deserve special note. They occupy the Bay in such abundance that they support a major commercial fishing enterprise. The adults of this category feed on the abundant supply of phytoplankton. Bluefish only enter the Bay as young adults or mature fish.

"One species that must be considered a migratory fish because of spawning practices is the eel. Eels reside in the Bay for long periods, but eventually migrate to their ocean spawning grounds in the Sargasso Sea.

"Other organisms appearing in the nektonic food web are some of the "lesser" members of the nekton mentioned earlier. Swimming crustaceans include shrimp, which spend most of their adult life near the bottom. Usually thought of as a "creeper", the blue crab has developed a swimming capacity with one pair of powerful legs that enable it to travel considerable distances in the Bay. Finally, numerous members of the shark family enter the Bay as do several marine mammals including the porpoise."

Bacteria

Bacteria are microscopic, free floating organisms. They are the most important element in the process of decomposition of dead plants and animals. By doing this, they make the nutrients in those dead organisms available to the food chain.

Many bacteria spend their entire lives in the Chesapeake. Others enter the Bay as part of human and animal waste or storm water runoff from the land. Most bacteria are harmless, but, there are some disease producing varieties.

Wildlife

The marshes and woodlands in the Chesapeake Bay area provide many thousands of acres of natural habitat for a variety of waterfowl, birds, reptiles, amphibians, and mammals. Chesapeake Bay is the constricted neck in the gigantic funnel pattern that forms the Atlantic Flyway. Most of the waterfowl reared in the area between the western shore of Hudson Bay and Greenland spend some time in the marshes of the Bay and its tributaries during their migrations. Good wintering areas adjacent to preferred upland feeding grounds attract more than 75 percent of the wintering population of Atlantic Flyway Canada geese. The marshes and grain fields of the Delmarva Peninsula are particularly attractive to Canada geese and grain-feeding swans, mallards, and black ducks. The Susquehanna Flats, located at the head of the Bay, historically supported huge flocks of American widgeon in the early fall, while several species of diving ducks, including canvasback, redhead, ringneck, and scaup, winter throughout Chesapeake Bay. About half of the 80,000 whistling swans in North America winter on the small estuaries in or around the Bay. While the Chesapeake is primarily a wintering ground for birds that nest further north, several species of waterfowl, including the black duck, blue-winged teal, and wood duck, find suitable nesting and brood-raising habitat in the Bay Region.

Many other species of birds are also found in the Bay area. Some rely primarily on wetlands for their food and other habitat requirements. These include rails, various sparrows, marsh wrens, red-winged blackbirds, snipe, sandpipers, plovers, marsh hawk, shorteared owl, herons, egrets, gulls, terns, and oyster catcher. Many of the above species are insectivores, feeding on grasshoppers, caterpillars, beetles, flies, and mosquitoes. Others feed on seeds, frogs, snakes, fish, and shellfish. There are numerous other birds which rely more heavily on the wooded uplands and agricultural lands for providing their basic habitat and food requirements. Among these species are many game birds including wild turkey, mourning dove, bobwhite quail, woodcock, and pheasant. It should be emphasized that some of these species require both an upland and wetland habitat. Modest populations of ospreys and American bald eagles also inhabit the Bay Region.

The Chesapeake Bay Region is also home for most of the common mammals which are native to the coastal Mid-Atlantic Region. The interspersion of forest and farmland and the proximity of shore and wetland areas form the basis for a great variety of ecological systems. The abundance of food such as mast and grain crops and the high quality cover vegetation found on the wooded uplands and agricultural lands support good populations of white-tailed deer, cottontail rabbit, red fox, gray fox, gray squirrel, woodchuck, opossum, and skunk. The various vegetation types found in wetland areas provide indispensible natural habitat requirements for beaver, otter, mink, muskrat, marsh rabbit, and nutria. In addition, there are numerous species of small mammals, reptiles, and amphibians which inhabit the Study Area and are integral parts of both the upland and wetland food cycles.

Plant and Animal Communities

Although the plants and animals of Chesapeake Bay have been treated separately in the previous discussion, in the real world they are inextricably bound together in communities. Bay communities are important because of the complex interactions between inhabiting organisms, both plant and animal, and between one community and another. In the "eelgrass" community, for example, the organic detritus formed by eelgrass, plus the microorganisms adsorbed on it, represent the main energy source for animals living in the community and for animals outside the community to which detritus is transported. In addition, eelgrass performs the following physical and biological functions:

1. It provides a habitat for a wide variety of organisms.

2. It is utilized as a nursery ground for fish.

3. It is a food source for ducks and brant.

4. The plant physically acts as a stabilizing agent for bottom sediments. This allows greater animal diversity.

5. It plays a role in reducing turbidity and erosion on coastal bays.

It is evident from the preceding discussion that Chesapeake Bay is an almost incomprehensibly complex physical and biological system. When the human element is added, the complexities and interrelationships become even more involved.

The foregoing paragraphs contain only a brief overview of the biota of Chesapeake Bay. More detail can be found in Appendix E of this report, the "Biota" sections of the Existing and Future Conditions reports and Phases I and II of the *Low Freshwater Inflow Study Biota Assessment* prepared by Western Eco-Systems Technology.

Socio-Economic Profile

As noted in Chapter 1, the Chesapeake Bay Study focuses on an area that includes those counties which are adjacent to or have a major social, economic or environmental interaction with Chesapeake Bay. For the purposes of the Low Freshwater Inflow Study, however, it was necessary to address the entire Chesapeake Bay Drainage Basin in computing future water consumption and the consequential potential reduction in freshwater inflow to Chesapeake Bay. The socio-economic analysis was therefore in two parts: a rather detailed analysis of the "Study Area" and a more general analysis of the entire Chesapeake Bay Drainage Basin.

Study Area

When Captain John Smith first explored the Chesapeake in 1608, it was an estuary which had yet to feel the impact of man to any significant extent. But, even before Captain Smith's voyage, people had settled on the shores of the Bay, drawn by its plentiful supplies of fish and game. These settlements were inhabited by Assateagues, Nanticoke, Susquehannanock, and Choptank Indians. It was the Indian that provided the names for many promontories of land and water courses. Later, more and more people moved into the Bay Region, attracted first by a soil and climate favorable to the growth of tobacco, and later by the development of major manufacturing and transportation centers. By 1970, 360 years after Captain Smith's voyage up the Bay, there were 7.9 million people living in the Bay Region.

During Colonial times, the Chesapeake Bay Region was one of the primary growth centers of the New World. However, after the decline of the region's tobacco industry in the 19th century, population growth began to lag. This period of relative stagnation lasted until World War II when large increases in Federal spending (especially on defense) stimulated employment and population growth in all the economic subregions. As shown in Table II-2, the areas around Washington, D. C. and Norfolk, Virginia, have experienced especially high rates of growth since World War II. Over half of the total population growth in the Bay Region between the time of the Jamestown settlement to the present occurred during the 1940-1970 period.

The majority of the inhabitants of the Chesapeake Bay Area are concentrated in relatively small areas in and around the major cities. Approximately 90 percent of the population resided in one of the Region's seven Standard Metropolitan Statistical Areas (SMSA) in 1970. The number of urban dwellers increased by almost 1.5 million during the 1960-1970 decade while the rural population remained virtually the same. People have tended to move out of the inner cities and rural counties and into the suburban counties. Thirty-five of the 76 counties and major independent cities in the area experienced a net out-migration during the 1960-1970 period. On the other hand, most of the suburban counties experienced growth rates in excess of 30 percent and in-migrations of at least 10 percent. In the Bay Region as a whole, net in-migration accounted for about one-third of

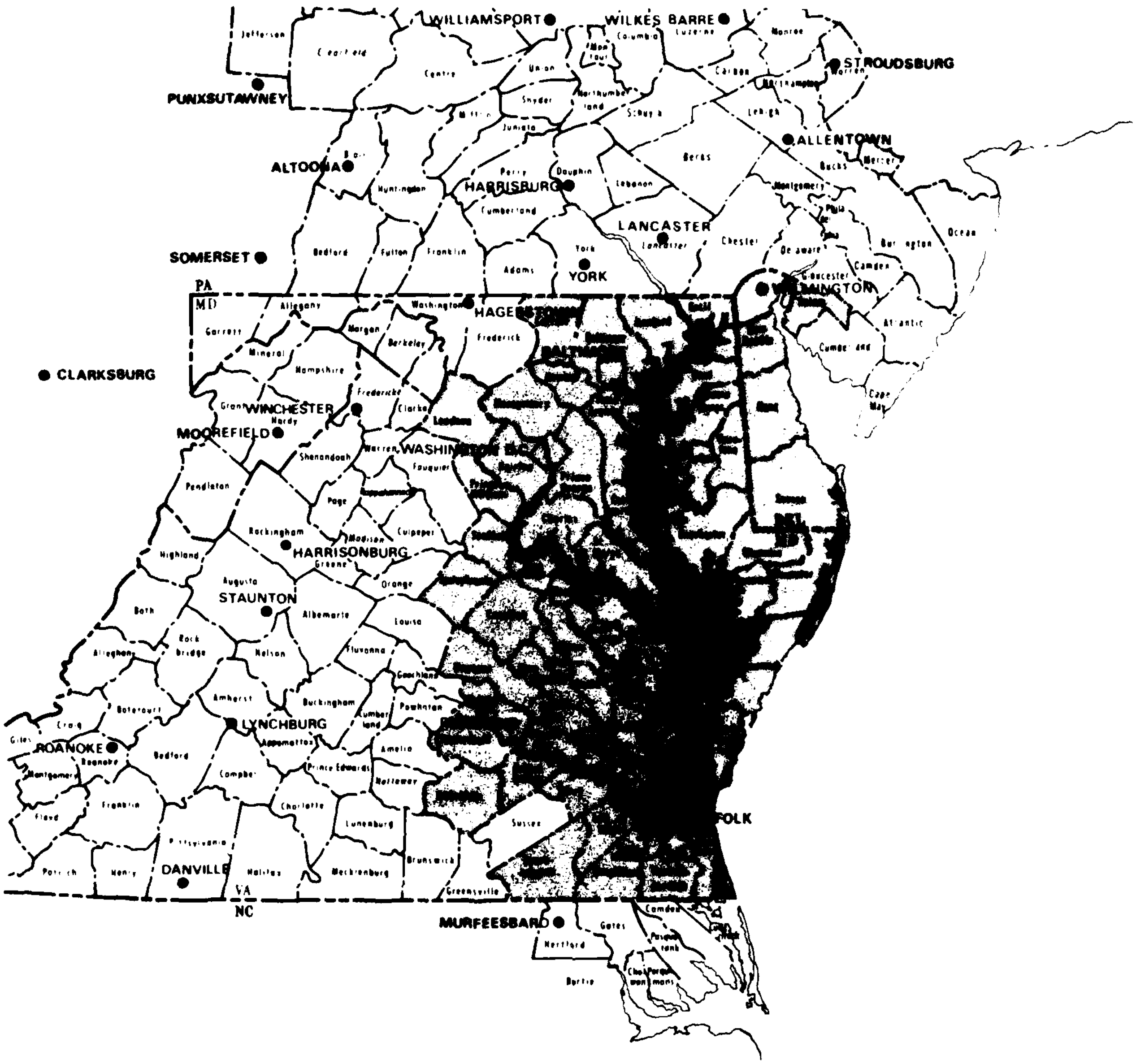


Figure II-9 Chesapeake Bay Study Area

TABLE II-2

Population Growth in the Chesapeake Bay Study Area During the 1940-1970 Period by Economic Subregion

Study Area Portions of BEA Economic Regions	1940 Population	1970 Population	Absolute Change	Percentage Change
Baltimore, Maryland	1,481,179	2,481,402	+ 1,000,223	+ 67.5
Washington, D.C.	1,086,262	3,040,371	+ 1,954,109	+ 179.9
Richmond, Virginia	437,103	728,946	+ 291,843	+ 66.8
Norfolk-Portsmouth, VA	467,229	1,121,856	+ 654,627	+ 140.1
Wilmington, Del. SMSA	248,243	499,493	+ 251,250	+ 101.2
Total Study Area	3,720,016	7,872,068	+ 4,152,052	+ 111.6
Total United States	132,165,129	203,211,926	+ 71,046,797	+ 53.8

Source: U.S. Census Data

the 1.5 million increase in population during the decade of the 1960's. Most of this in-migration was in response to large increases in employment opportunities.

In 1970, there were approximately 3.3 million people employed in the Study Area. About 91 percent of these worked in one of the Region's seven SMSA's. During the 1960-1970 period, total employment increased by about three-quarters of a million jobs, or approximately 30 percent. The National gain during the same period was 19.5 percent.

Compared to the Nation as a whole, the Bay Region has a lower proportion of workers in the blue-collar industries such as manufacturing and mining and a higher proportion in the white-collar industries such as public administration and services. Since employment in the white-collar industries tends to be less volatile, the Study Area has had consistently lower unemployment rates over the last several decades than the Nation. Also contributing to these relatively stable employment levels are the large numbers of workers whose jobs depend on relatively consistent Federal government spending.

Per capita income in the Bay Area was $3,694 in 1969, which was about 9 percent higher than the National figure. Median family income levels ranged from $16,710 in Montgomery County, Maryland, (one of the highest in the Nation), to $4,778 in Northampton County, Virginia. As shown in Table II-3, there was a significantly higher proportion of families in the over $15,000 income bracket and fewer families whose incomes were below the poverty level in the Bay Area than in the Nation.

Figure II-10 shows, by economic area, the 1970 population of the Study Area as well as the projected population and employment for the years 1980, 2000 and 2020. Future population is based on the OBERS Series E projections prepared by the Department of Commerce. Most of the work on this study was done before the actual 1980 population and employment for the Study Area became available.

By the year 2020, the population of the Study Area is expected to be over 14 million people. This is nearly 80 percent

TABLE II-3

Family Income Distribution for the Chesapeake Bay Study Area and the United States, 1969

	Percent Below Poverty Level	"Middle" Income Families	Percent Above $15,000
Study Area	11.2	61.3	27.5
United States	12.2	68.6	19.2

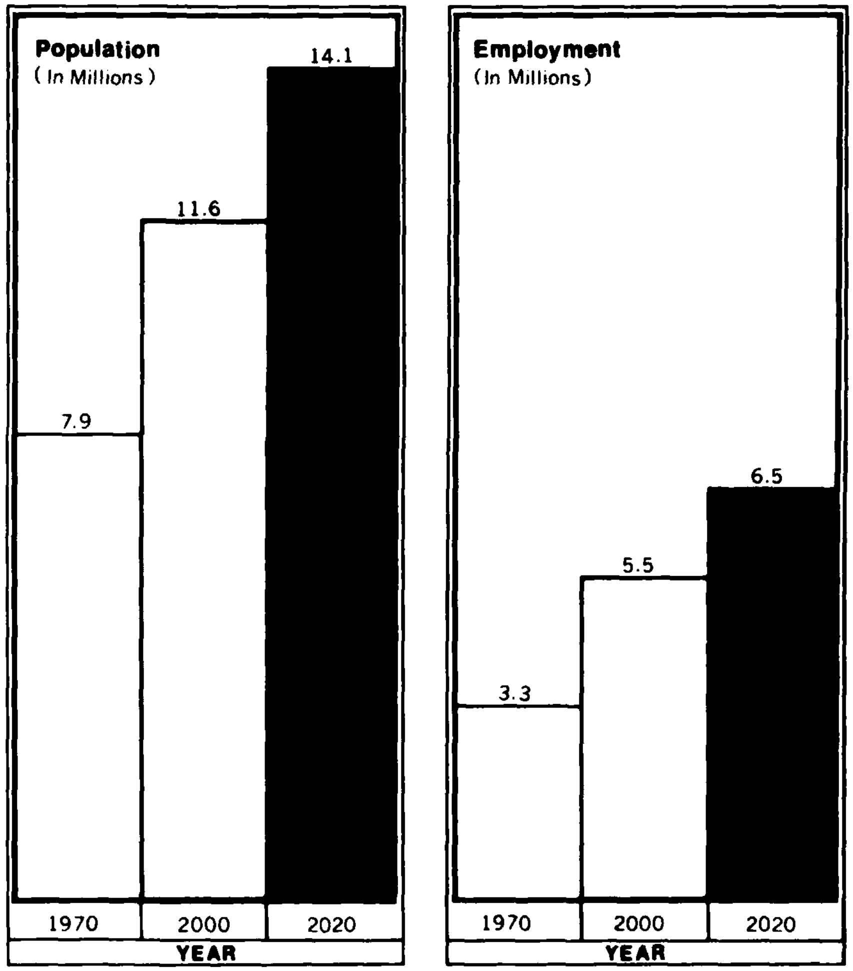


Figure II-10 Population and Employment Projections for the Study Area

more than the 1970 population of 7.9 million people. Nearly 70 percent of the increase is expected to take place in the Washington, D. C. economic area where the population will increase by about 140 percent. The Richmond and Wilmington areas are also expected to grow at a faster rate than most of the other areas with total increases of 65 percent and 76 percent respectively. On the other hand, the Baltimore area is expected to grow only 32 percent and the Norfolk-Portsmouth subregion 28 percent.

Nearly 6500 people are expected to be employed in the Study Area by the year 2020. This is nearly double the 1970 employment level. As with population most of the employment as well as employment growth (15 percent) will be in the Washington, D. C. region. Most of these people will be involved in "white collar" type work or in wholesale and retail trade.

Both the Wilmington and Richmond areas will also experience increases in employment with total growths of 103 percent and 79 percent respectively. Employment in the Baltimore area is expected to grow only 47 percent, while the Norfolk-Portsmouth area will have a growth of only 39 percent. As in the rest of the Nation, there will be a trend toward "white collar" type work.

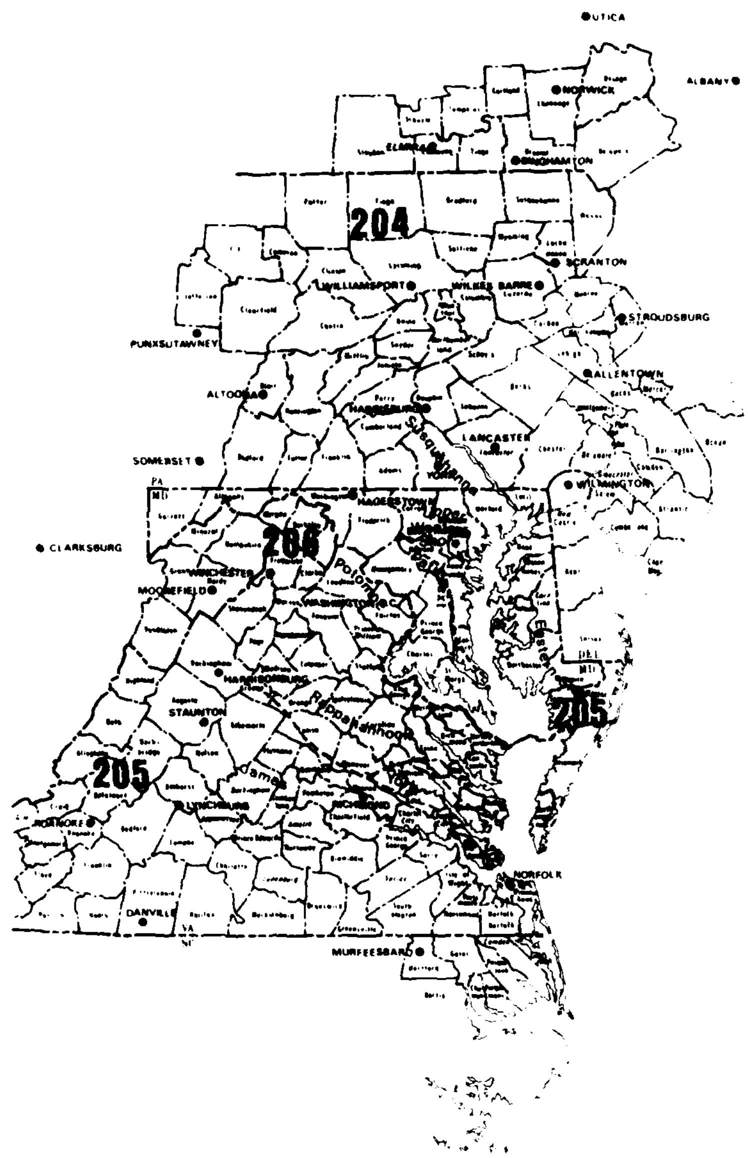


Figure II-11 Economic Areas — Chesapeake Bay Drainage Basin

Chesapeake Bay Drainage Basin

The economic and demographic projections prepared by the Department of Commerce are normally done on the basis of economic areas whose boundaries seldom coincide with those of river basins. Such was the case with the OBERS Series E projections. However, in the Second National Water Assessment published in 1978 by the U. S. Water Resources Council, the OBERS Series E projections were presented by subregions that did coincide with river basin boundaries. These were called ASR's.

As shown in Figure II-11, the Chesapeake Bay Drainage Basin is made up of ASRs 204, 205 and 206. ASR 204 coincides with the Susquehanna River Basin, while ASR 206 is the Potomac River Basin. Included in ASR 205 are Baltimore and the Upper Western Shore, the Eastern Shore and the Rappahannock, York and James River Basins.

The National Assessment presented population and employment data only for the years 1975, 1985 and 2000. These are shown on Figure II-12. Also shown on this figure are projections for the year 2020. These were computed using the original Series E projections as the bases for rates of growth between the years 2000 and 2020.

In 1975, about 75 percent of the people in the drainage basin lived in ASRs 205 and 206. In the future, these areas are expected to grow at a more rapid rate than the remainder of the basin. This reflects the fact that most of the population growth will center around the large metropolitan areas located in ASRs 205 and 206.

The rate of growth of both population and employment in the Susquehanna River Basin (ASR 204) will be less than one half that of the other two subregions. Its share of the population will decrease from about 29 percent in 1975 to about 23 percent in 2020. Employment will increase at a rate of only 0.9 percent per year as compared to 1.8 percent per year for ASR 205 and 2.3 percent per year for ASR 206.

In 1975, employment in the Susquehanna River Basin was somewhat below that of the Nation. A worker was more likely to be a "blue collar" worker than a "white collar" worker. The people living in or near the cities were generally more affluent than those living in the more rural areas. Partially counteracting the lower income level, the cost of

living is generally lower in the Susquehanna Basin than it is in the big metropolitan areas. In the future, the economy of this basin is expected to become similar to the rest of the nation with a trend toward "white collar" type work.

It should be noted that most of the basic data used in this Chesapeake Bay Low Freshwater Inflow Study were prepared prior to 1980. At that time, only the OBERS Series E projections were available. Consequently all work on the study was based on these projections. In 1983 the Department of Commerce published a new set of projections called OBERS 80. These data were based on the 1980 census. Generally, OBERS 80 data indicate that the year 2020 population and employment levels are expected to be somewhat less than those predicted by Series E. The effects of these revised projections on the study findings are addressed in the sensitivity analysis contained in *Appendix A, Problem Identification* and summarized later in this *Main Report*.

Institutional Framework

For the purpose of this study, an institution is an organization which uses certain administrative, political and social processes to implement and/or manage water use and control in an area. An institution may be a formal (i.e. formed by law or contract) or an informal (i.e. formed by consensus of people, usually with no strict legal basis) body, group, or agency. The purpose of the institutional analysis was to identify in general terms the existing institutional framework responsible for water use and/or management in the Chesapeake Bay Basin. Included in this section of the report is a brief discussion of both the riparian water use principles applicable in the Bay Region and water resource responsibilities of many Federal, state and local agencies in the Region.

The Eastern States, which include the Chesapeake Bay Basin states, are governed by the riparian doctrine. This system emphasizes the rights of water users in common without regard to specific quantities, times, or places of use. Rights under riparian doctrine are dependent upon ownership of land contiguous to the water supply. All such owners have equal rights to co-share in the use of the waters, so long as each riparian is reasonable in its use. Riparian rights are rights of use, not ownership, of flowing waters.

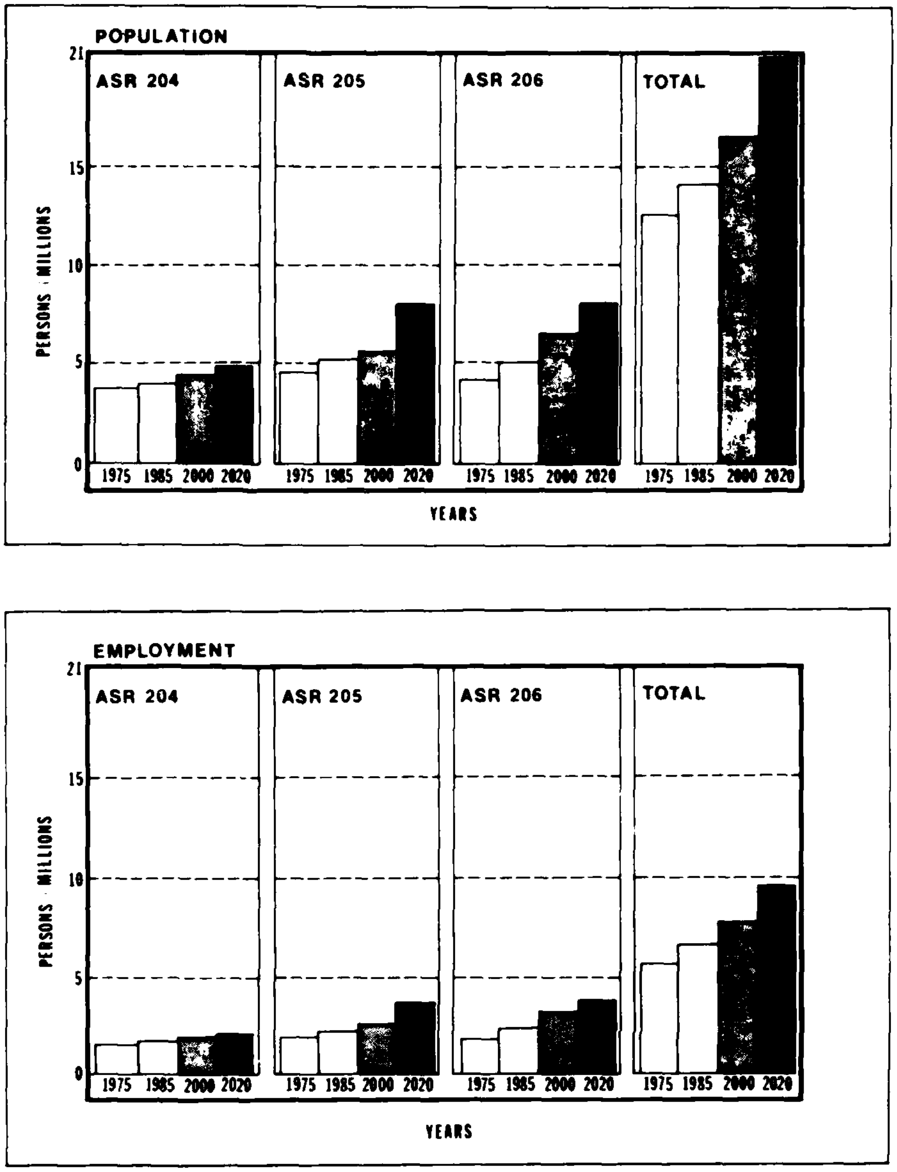


Figure II-12 Series "E" Projections for the Chesapeake Bay Basin

Federal Agencies

The concept of Federal responsibility for comprehensive development of the water and related land resources is embodied in legislative enactments under the *Commerce and Welfare Clauses* of the Constitution, as well as with the gradual growth of a body of policy by repeated authorization of specific types of projects. The fundamental objective of the Congress in authorizing Federal participation in resource development has been to insure that the Nation's resources make an optimum contribution to the health and welfare of its people. At the same time, the Congress seeks to maintain a reasonable balance between the powers assumed by the Federal government and those to be left with the states, local governmental entities, and private enterprise. The *Water Resources Planning Act of 1965* officially identified this as National Policy and emphasized local state-Federal cooperation.

There are basically three ways in which the Federal government contributes to projects of regional or local benefit: directly, indirectly, and financially. Direct participation involves research, planning, preparation, operation and maintenance (or any combination of these) of one or more elements of a project by the Federal government itself. Indirect aid includes services or information, advice and assistance for activ-

ities of other levels of government in research, planning, engineering, and technical areas, as well as the use of Federal facilities. Financial aid is usually in the form of direct grants, perhaps tied to specific purposes; loans (repayable or nonrepayable), advances, and purchase or underwriting of bond issues. Federal agencies involved in water resource management include the Agricultural Research Service and the Soil Conservation Service of the Department of Agriculture; the Economic Development Administration, National Marine Fisheries Service and National Oceanographic and Atmospheric Administration of the Department of Commerce; the Geological Survey and Fish and Wildlife Service of the Department of the Interior, the Department of Housing and Urban Development; the Environmental Protection Agency, and the Corps of Engineers.

Interstate and Basin Institutions

There are several institutions in the Chesapeake Bay area which have water resource related responsibilities on an interstate level. In 1940 Congress authorized Maryland, Virginia, Pennsylvania, and West Virginia to enter into a compact which created the Interstate Commission on the Potomac River Basin (ICPRB). The purpose of the ICPRB is to regulate, control, prevent, or otherwise render harmless the pollution of the waters of the Potomac drainage area by sewage, industrial and other wastes.

Over the course of the last decade ICPRB has worked with the Corps of Engineers, local governments and the water suppliers in the Metropolitan Washington Area to develop a long term solution to the area's water supply needs. In developing this solution, the involved parties have by necessity, addressed the amount of water that must be allowed to "flow-by" the water supply intakes and enter the Potomac Estuary. The document that serves as the legal basis for the Potomac River flow-by is the Potomac Low Flow Allocation Agreement (LFAA). The present recommended minimum "flow-by" into the Potomac Estuary is 100 mgd or 155 cfs.

The Susquehanna River Basin Commission was created in 1963 as the result of a compact between Pennsylvania, Maryland, New York and the Federal government. The Commission coordinates basin-wide water resource planning based on a compre ensive basin plan. This Commission serves as a water resources project development, management and operating agent, as it determines necessary. As the need is demonstrated, it develops a capability for coordination and management of funding and conduct of public works programs and projects in the basin. Some examples of projects and programs the Commission considers are: allocations, withdrawals, and diversions of water; development of nonstructural and structural measures for flood damage reduction, water supply storage, low flow augmentation, and water related recreation; water quality standards and their application; and protection and preservation of natural amenities.

In matters pertinent to the Low Freshwater Inflow Study, SRBC has established a regulation to control consumptive use during low flow conditions. Consumptive users must provide water in the total amount consumed during periods when the flow in the streams from which the supply is being taken drops below a predetermined minimum rate, the 7-day, 10-year low flow (streamflow rate during seven consecutive days with a 10 percent chance of occurring in any year, Q7-10). Consumptive users must comply with the new regulation after July 1984.

Also related to the minimum freshwater inflow into Chesapeake Bay was a June 1982 ruling of the U. S. Federal Energy Regulatory Commission (FERC). In reviewing a request to extend the license for the Conowingo Hydroelectric Project No. 405, FERC addressed minimum flow releases from the project. The project is located on the main stem of the Susquehanna River only several miles upstream from the head of tide. Thus, the minimum releases from the project are in fact the minimum flow into the Bay.

FERC ordered the licensees to maintain the following interim minimum flow releases or the mean daily discharge of the Susquehanna River flow, whichever is less:

April 15—June 15	—5,000 cfs
June 15—September 15	—5,000 cfs—as measured at the Marietta, Pennsylvania U.S. Geological Survey Gauging Station #01578310 at Conowingo Dam
September 15—April 15	—No minimum flow required

The Chesapeake Bay Commission was created by the 1980 General Assemblies of the State of Maryland and the Commonwealth of Virginia. The primary purposes of the Commission are to assist the legislatures of the two states in responding to problems of mutual concern, and encourage cooperative coordinated planning and action by the signatories and their executive agencies.

The Metropolitan Washington Council of Governments (MWCOG), created in 1965, consists of sixteen major local governments — the District of Columbia, two major Maryland and four Virginia counties, and nine cities. The Council is empowered to advise and assist local governments of the region to: (1) Identify mutual problems, (2) develop and promote a comprehensive plan, (3) seek mutually desirable policies, (4) support and promote concerted action among members, (5) represent members on regional matters.

The Atlantic Seaboard States (including Maryland and Virginia) have entered into a compact for the better utilization of fisheries. The activities of the Atlantic States Marine Fisheries Commission include coordinating states' regulatory powers, drafting and recommending state and Federal fishery legislation, promoting marine research, consulting and advising state agencies on environmental and fish resources.

The Potomac River Fisheries Commission (PRFC) is a Maryland and Virginia bi-state commission. The Commission is responsible for the establishment and maintenance of a program of conservation and improvement of the seafood resources of the Potomac River. The regulation and licensing of fisheries in the Potomac River are also functions of this Commission.

State and Local Agencies

The Chesapeake Bay and its shores are owned by the states and their local subdivisions. Included in the following paragraphs are a description of the primary responsibilities of those state agencies concerned with water resources management in the Chesapeake Bay Region.

The State of Delaware does not play a major role in the protection or the enhancement of water resources within

the Bay. The jurisdiction of the state over water entering the Bay is confined to the headwaters or tributaries on the Eastern Shore and to the Chesapeake and Delaware Canal. Delaware's water resources management agency is the Department of Natural Resources and Environmental Control. The Water Resources Section of the Environmental Control Division, Department of Natural Resources and Environmental Control, focuses on three mission areas: water supply (allocation for consumption), planning (with respect to PL 92-500), and water pollution control (NPDES permit program, review of construction grant permits, and compliance monitoring program). A technical services group provides sampling and analytical services in support of the Division's responsibilities. The Bureau of Environmental Health is responsible for the quality of potable water and general sanitation within the State.

In the District of Columbia, water management in conducted by the Department of Environmental Services (DES). Responsibilities of DES include: (1) planning, providing, operating, and maintaining sanitary sewerage systems and facilities within the District, (2) preparing and recommending environmental criteria and standards as well as rules and regulations for their enforcement, (3) conducting planning research and monitoring of potential environmental quality problems.

With respect to water supply for the District, the legal position is encapsulated within the power of the U. S. Government. Congress has dealt with the water needs of the District by the establishment of the Washington Aqueduct and delegation to the Chief of Engineers the planning and operational responsibilities relative to providing the District and certain nearby suburban communities with their supply of potable water. *(Act of March 3, 1959;* 11 Stat. 435).

In Maryland most water management decisions and controls are handled by major state agencies (described below), although water supply services are also provided by local governmental units, state-created sanitary districts, county sanitary districts and planning commissions, and private companies. County sanitary commissions and larger municipalities are responsible for construction and maintenance of water and sewer facilities. County planning commissions prepare and adopt general development plans for guiding development in each of the counties. Environmental health services are the responsibility of county health departments. The health departments issue permits for sewage treatment plant operations.

The Maryland Department of Natural Resources (DNR) was established to review, unify, coordinate and promulgate all natural resources policies within Maryland. The central agencies within DNR which deal with water resource management are the Water Resources Administration, the Tidewater Administration, the Wildlife Administration, and the Wetland Administration.

The Maryland Department of Health and Mental Hygiene exercises responsibility for the general supervision and control over the sanitary conditions of the State waters as related to public health. This responsibility is conducted by the Department's Office of Environmental Programs.

The New York State jurisdiction over waters in the Chesapeake drainage area are confined to 25 percent of the Susquehanna River Basin. In New York, the majority of water management activities are the responsibility of the Department of Environmental Conservation.

A portion of the Potomac River Basin and 76 percent of the Susquehanna River Basin are under the jurisdiction of the Commonwealth of Pennsylvania. The responsibility for the regulation and development of the Commonwealth's natural resources, including management of activities that affect water and land resources, minerals, and outdoor recreation are under the Department of Environmental Services (DER). The DER is also responsible for the control and abatement of water and air pollution. The two main offices dealing with water resources management within the Department are the Office of Environmental Protection and the Office of Resources Management.

Virginia follows the reasonable use formula of riparian law with respect to water in natural streams. The Virginia courts have evolved a doctrine which gives high priority to domestic uses. These are defined as uses to serve household needs, watering of livestock, and irrigation of the household gardens. This priority is so strong that a particular riparian owner is permitted to exhaust the flow of a stream in order to serve his domestic needs. Other uses, such as agricultural, industrial, and municipal are subject to the balancing concept of the reasonable use doctrine.

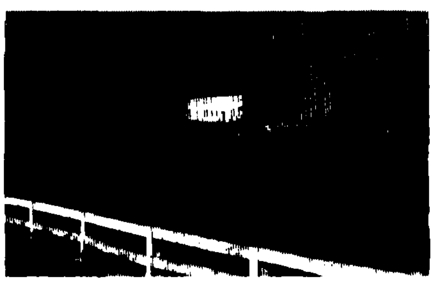
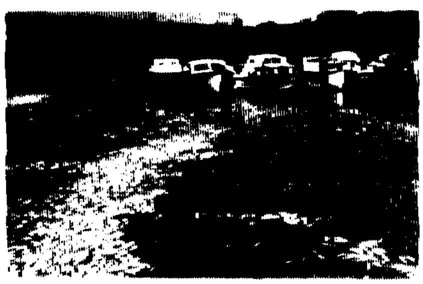
Localities are granted the authority to engage in water supply services. This could be accomplished by several types of semi-autonomous bodies, sanitary districts, water authorities, and service districts. The Commonwealth is also divided into 22 planning districts which serve as local planning units for water quality and supply planning efforts.

There are several agencies in the Commonwealth of Virginia that have water resources responsibilities. The two major regulatory agencies are the State Water Control Board and the Virginia Marine Resources Commission. Other agencies include the State Department of Health, the Commission of Game and Inland Fisheries, the Division of Parks, the Council on the Environment, and the State Corporation Commission. All of the above agencies are under the jurisdiction of the Secretary of Commerce and Resources with the exception of the Department of Health which is under the jurisdiction of the Secretary of Human Resources and the State Corporation Commission which is an independant agency.

West Virginia contains and has jurisdiction over a largely rural portion (24 percent) of the Potomac River watershed. The major water resources management agency is the Department of Natural Resources. The objective of the Department is to provide a comprehensive program for the exploration, conservation, development, protection, enjoyment and use of the natural resources of the State of West Virginia. West Virginia participates actively in the Interstate Commission on the Potomac River Basin (ICPRB). Descriptions of the responsibilities of the various agencies are shown in *Appendix A, Problem Identification.*





CHAPTER III

Problem Identification

Introduction

Like all estuaries, Chesapeake Bay is dependent on the inflow of freshwater to maintain its salinity regime. The many species that live in the Bay year-round and others that use it only in various portions of their life cycle are generally able to survive in the natural daily, seasonal and yearly variations in salinity. But, drastically reduced freshwater inflows during a period of drought, or reductions of less magnitudes over a longer period of time, can impose environmental stress by threatening the health or even the survival of species sensitive to particular ranges of salinity, or by limiting the spawning opportunities of certain other estuarine species. Changes in freshwater inflow can also alter existing estuarine flushing characteristics and circulation patterns. In short, the character of Chesapeake Bay and the health and well being of the ecosystem are dependent on established physical, chemical, and biological patterns in the Bay. These are, in turn, intimately related to the volumes of and seasonal variations in freshwater inflows.

The Chesapeake Bay and its tributaries are a large source of water supply for the communities, industries, and farms located along or near its shores. People use the water from the Bay and its tributaries for a variety of purposes including drinking, washing clothes and dishes, bathing, lawn sprinkling, and washing their cars. Industries use it in their manufacturing processes, while, farmers irrigate the crops and water the livestock.

Most of this water is returned to the Bay or its tributaries after it has been used. The part that is not returned is called the consumptive loss. Consumptive losses occur nearly every time water is used. For instance, a typical community will return to a stream only 75 percent to 90 percent of the water it withdraws from it. The rest is lost through pipe leaks, lawn sprinkling and many other ways. Over 75 percent of the water used for irrigation never returns to the stream or takes so long to return that for all practical purposes is considered lost. From 3 to 26 percent of the water withdrawn by industries is lost. This is being aggravated by a definite trend toward increased use of evaporative cooling processes. The loss of water associated with these processes is often markedly greater than in other types. For instance, in electrical power generation, only 2 percent of the water is lost if once through cooling is used. Cooling towers increase this over six fold.

In the future, every tributary to Chesapeake Bay may be subjected to the consequences of rapidly increasing consumptive uses of water. This means that by the year 2020 there will be a marked reduction in the amount of freshwater flowing into Chesapeake Bay. The result of this will be an increase in the Bay's salinity levels.

The magnitude of these increased salinities and their socio-economic and environmental consequences was the focus of the problem identification stage of this study. The work required to address them was done in several steps:

1. Computation of the water supply demands which occurred in the base year 1965 and those expected in the year 2020. In order to facilitate these computations and to provide appropriate input to the hydraulic model test, the Chesapeake Bay Basin was divided into 21 sub-basins contiguous to the freshwater inflow points shown on Figure III-1.

2. Computation of consumptive losses for the years 1965 and 2020. The incremental difference between those two sets of consumptive losses yield the amount by which freshwater inflows would be reduced between the years 1965 and 2020.

3. Conducted a test on the Chesapeake Bay Model to determine the changes in salinity caused by reduced freshwater inflows. Four conditions of freshwater inflow are simulated:

a. Base Average—long term average freshwater inflow to Chesapeake Bay.

b. Future Average—Base Average freshwater inflows reduced by the increase in consumptive losses expected between the years 1965 and 2020.

c. Base Drought—the freshwater inflows which occurred in the years 1963 through 1966 adjusted to reflect reservoirs which were constructed between 1965 and 1980.

d. Future Drought—Base Drought freshwater inflows reduced by the increase in consumptive losses expected between the years 1965 to 2020.

4. Determination of how the changes in salinity affected the biological resources of the Bay and the municipalities and industries that use the estuary for a water supply source. This was done in terms of economic, environmental and social impacts.

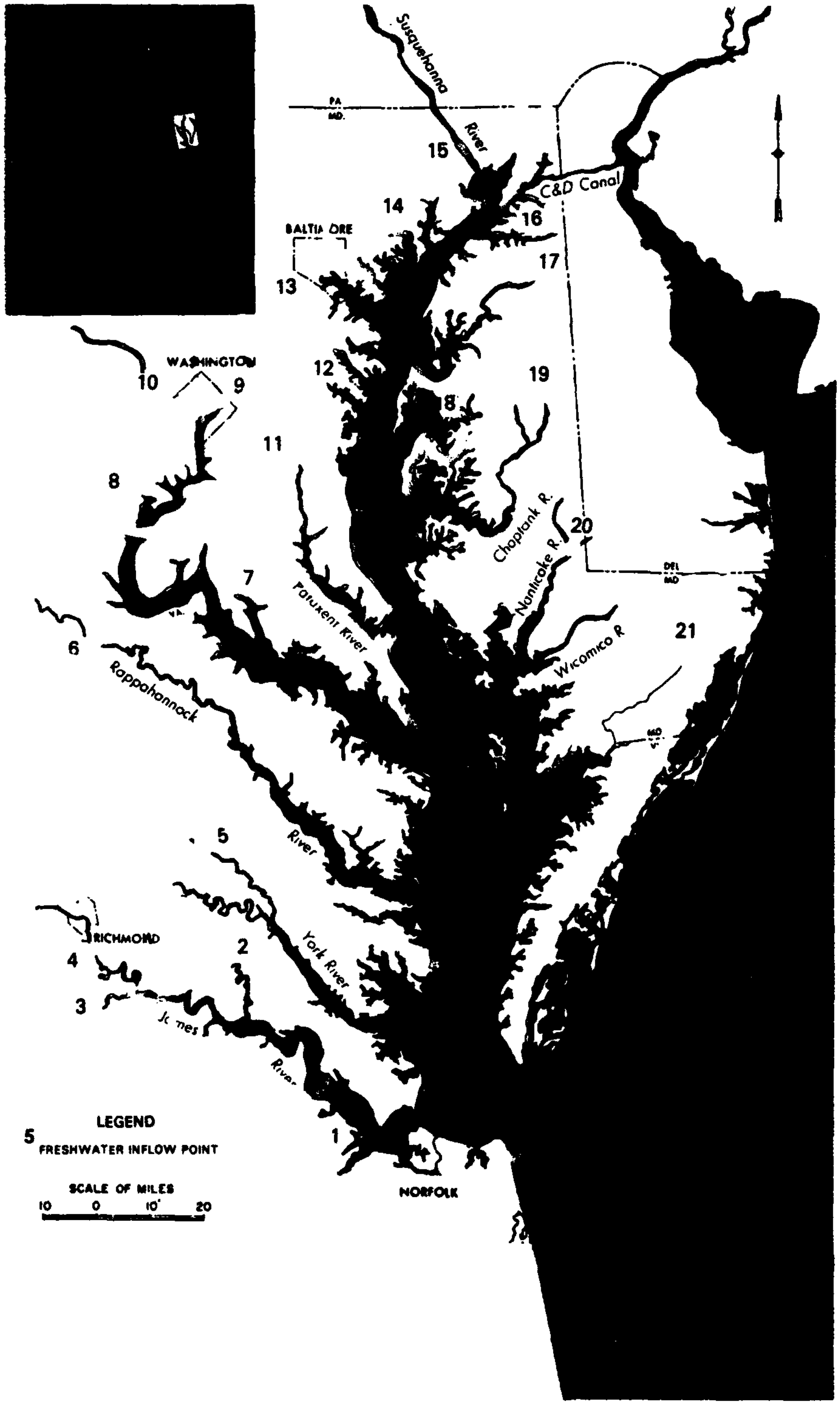


Figure III-1 Freshwater Inflow Points

Water Supply Demand and Consumptive Losses

Water supply demands and consumptive losses are addressed in detail in *Appendix C, Hydrology.* Generally, they were computed for the following six types of uses:

1. Public, domestic and commercial
2. Manufacturing
3. Power
4. Irrigation
5. Livestock
6. Minerals

Water Demands

Shown on Figure III-2 are the year 1965 and 2020 water supply demands for each of the water use categories. Data was not available for 1965 water use in the electrical power generating unit industry. Water use is expected to increase substantially in every category except manufacturing and livestock. In manufacturing, it is anticipated that new technology will reduce the amount of water needed in industrial processes. Therefore, large increases in production can be achieved with only a small increase in the amount of water withdrawn. Only a small growth in the raising of livestock is anticipated.

Consumptive Losses

As can be seen on Figure III-3 a five-fold increase in consumptive losses of water is expected by the year 2020. By far, the largest increase will be in electrical power generation (over 2,500 percent). This reflects both an increase in the amount of power to be generated and the trend toward the use of cooling towers.

Despite the fact there will be only a modest rise in the amount of water withdrawn by industries, consumptive losses will increase over 500 percent. This is due to the fact that much of the water that will be withdrawn will be used to make up for the water which is lost in evaporative cooling processes.

Freshwater Inflows

By the year 2020, an alarming portion of the freshwater inflow to Chesapeake

Bay will be lost through consumptive use of water. This is vividly illustrated in Figure III-4 where the consumptive losses are compared with both long term average freshwater inflows and the average monthly inflows to the Chesapeake during the 1960's drought. June 1965 through May 1966 is illustrated, as this is the time period upon which problem identification focused.

The consumptive losses range from 2 to 11 percent of the long term average monthly freshwater inflows. The maximum of about 11 percent occurs during the summer months of July, August and September. The importance of these reductions should not be underestimated as this would represent a permanent increase in the salt levels of Chesapeake Bay.

The year 2020 consumptive losses are a significant portion of the freshwater inflows expected during a drought; especially in the summer and early fall. During July, August and September the losses vary from over 15 percent to over 30 percent of the total freshwater inflow into Chesapeake Bay. It should be noted that projected consumptive losses actually exceed the amount of water that was in the Potomac River in July and August of 1966.

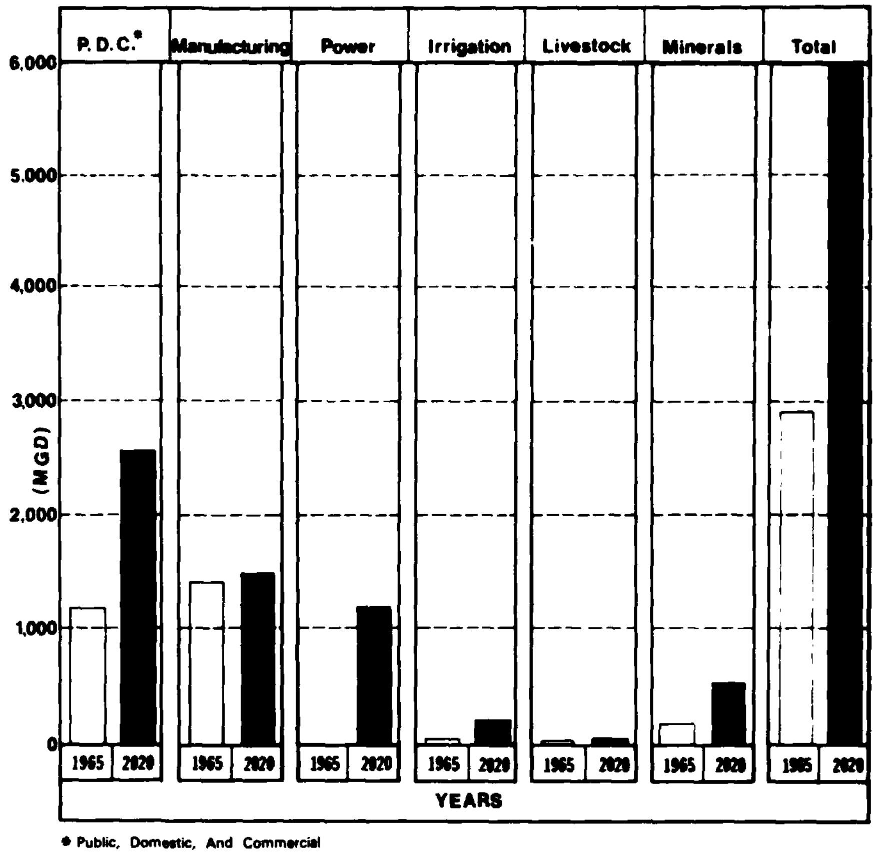


Figure III-2 Water Supply Demands

Problem Identification Hydraulic Model Test

The primary purpose of the Low Freshwater Inflow Problem Identification hydraulic model test was to determine how salinites in the estuary would be affected by droughts and consumptive use of water. In order to accomplish this, the test was divided into two parts; a base test and a futures test. In the base test, the freshwater inflows that occurred during the 1963 to 1966 drought were simulated. The drought was followed by several repetitions of an average inflow year. In the futures test, both the average and drought hydrographs were reduced by the expected increase in consumptive losses between the years 1965 and 2020.

It was found that consumptive losses in general cause a saltier Chesapeake Bay. The magnitude and structural variations in salinity response as a result of these losses depend on the specific hydrodynamic characteristics of a given area and its proximity to the riverine system or the ocean. On the

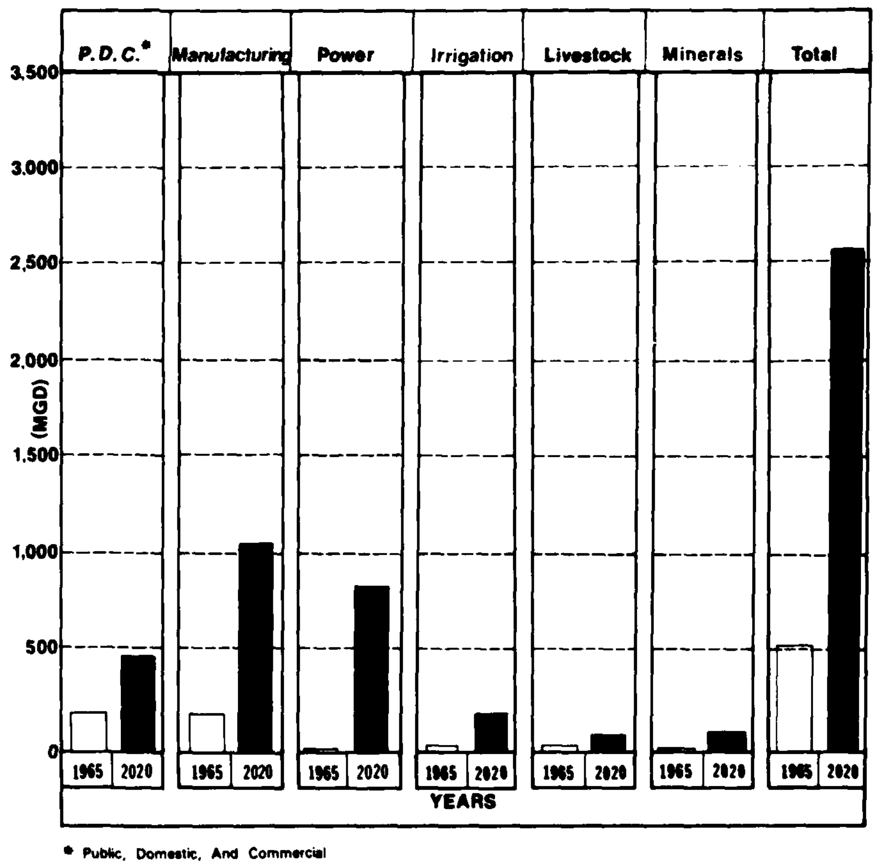


Figure III-3 Consumptive Losses

average however, it appears that the Chesapeake Bay salinities would increase a maximum of 2 to 4 parts per thousands due to consumptive losses of water. Also, it appears that drought salinities are as much as 5 ppt higher than long term average salinities.

Of particular significance is the penetration of higher level salinities into the estuary. This phenomenon is illustrated on the accompanying isohaline maps (Figures III-5 and 6). These maps compare base and future seasonal average salinities for both drought and average conditions during two different seasons of the year. Particular note should be taken of how the lines of equal salinity are located much further upstream in the futures test than they are in the base test. More detail on the test results are in *Appendix D, Hydraulic Model Test*.

Problems and Needs

The problems caused by increasing salt levels in Chesapeake Bay have been identified as a function of socio-economic and environmental values. Of primary concern are the anticipated changes in the populations of aquatic plants and animals resulting from these increased salinities. These changes were addressed from not only an ecosystem perspective, but also from the viewpoint of their implications to such resources as commercial fishing and recreation. Also the municipalities and industries that use the estuary as a water supply source were inventoried to determine if there would be any adverse socio-economic or environmental impacts resulting from both long term and average or drought related increases in salinity.

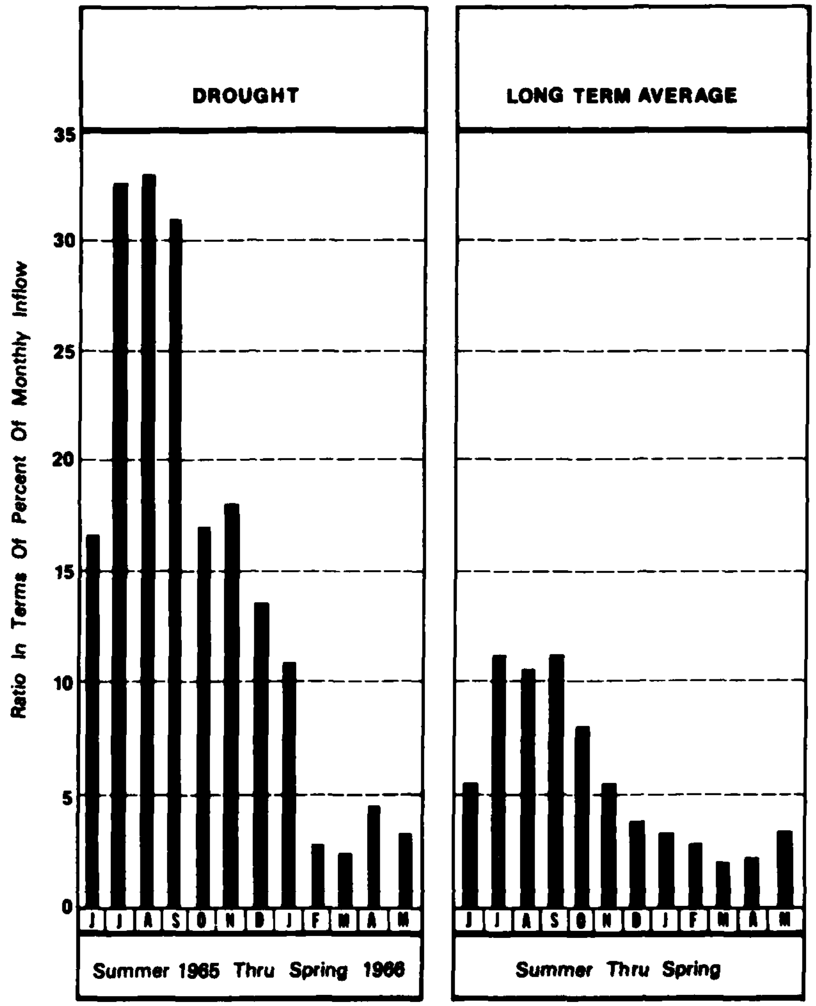


Figure III-4 % of Consumptive Losses of Stream Flow

Environmental Quality

As far as could be determined, there were few if any established procedures available for determining the effects of salinity changes on estuarine plants and animals. A cooperative effort to develop an evaluation tool was therefore instituted among the Fish and Wildlife Service, the Steering Committee, Western Eco-Systems Technology and the Corps of Engineers. This yielded a state of the art technique involving:

1. Mapping the habitat for 57 selected plants and animals.

2. Estimating the changes in habitat caused by changes in salinities.

3. Estimating how the changes in habitat affect the population of each selected plant or animal.

The potential habitat for each species was mapped for each of the four inflow conditions simulated on the Chesapeake Bay Model. (Base and Future Average and Base and Future Drought). The criteria used in this mapping were the critical season for the organism, salinity, substrate, and depth. These maps are in *Appendix F-Map Folio*. A sample map is shown in Figure III-7.

The Fish and Wildlife Service formed a panel of expert scientists to determine how the changes in habitat affected the populations of the plants and animals. This panel was called the "Biota Evaluation Panel." Its members compared the habitats under base conditions with those under future conditions. They also compared drought habitat with average habitat to ascertain if there were adverse impacts associated with the Base Drought natural conditions. The findings of the panel are presented in a report entitled *Estimated Biological Responses to Potential Reductions of Freshwater Flow Into the Chesapeake Bay*, dated April 1983. They are summarized on Table III-1. More detail is in *Appendix A, Problem Identification* to this report.

Aquatic Resources. Table III-2 shows the magnitude of the impacts on the plants and animals that are adversely affected under Future Average, Base

Drought and Future Drought flow conditions. The table also shows whether the problems are of local, regional and/or National significance. Local effects are those felt to be of concern at the community level or within one or two segments of the Bay or a tributary. These problems are assumed to be of a nature that would be of particular concern at only the county or community level. Regionally important effects would be of a magnitude sufficient to attract attention at diverse locations around the Bay and perhaps in state legislatures. Nationally important impacts are those that would attract attention nationwide and perhaps legislative action by the Congress of the United States.

In general, changes in habitat due to long term average increases in consumptive losses (Future Average conditions) are small. However, large losses are expected in the habitat of disease free oysters, soft clams and *Macoma.*

Much larger losses are expected during both Base and Future Drought events. Plants and animals particularly affected include anadromous fish, low salinity SAV, soft clams, *Macoma* and disease free oysters. Certain species will be more affected by reductions in food supply (ducks) or increases in predation or disease (oysters) than by direct losses in habitat. Also some organisms will recover much more rapidly from the effects of a drought. Small, rapidly growing organisms such as plankton, would be expected to repopulate affected areas rather quickly. On the other hand, it could take as long as a decade or more for some of the benthics and SAVs to recover from the effects of a drought.

The anticipated decline in oysters under all three reduced freshwater inflow conditions is particularly disturbing. Although oysters generally thrive in areas where salt levels are high, so do diseases such as dermo and MSX. The problem is that oysters move into new areas and recolonize very slowly while its diseases and parasites can spread rapidly; especially where salt levels are greater than 15 ppt. The Biota Evaluation Panel has estimated that the losses in oysters due to this phenomenon would be very large and could reach the levels shown on Table III-3. It should be noted that these conclusions have been partially substantiated during the past several years. Freshwater inflows to

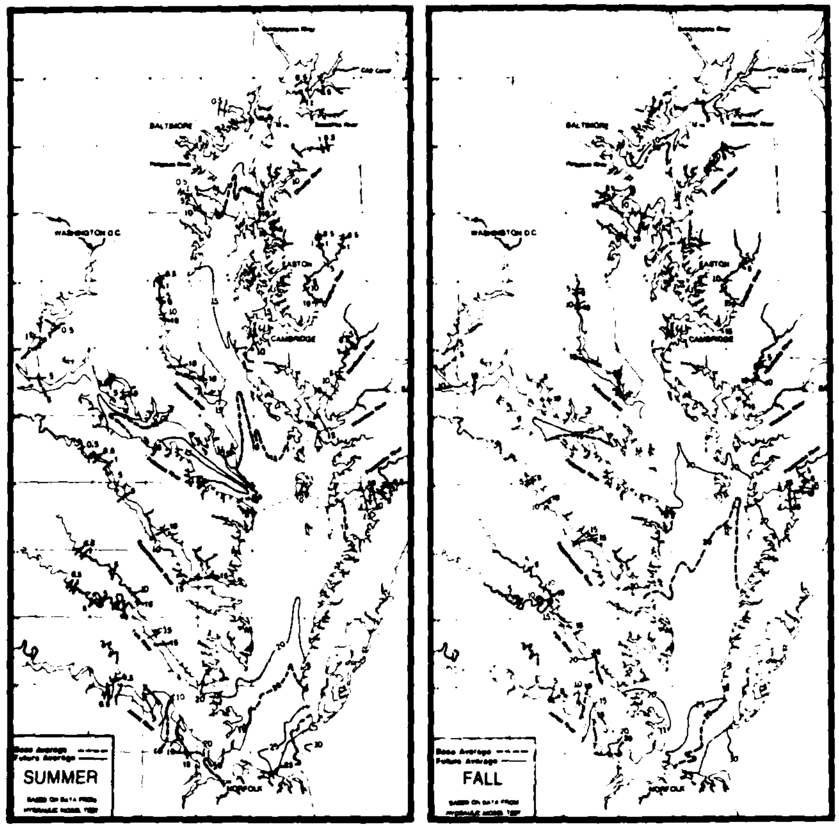


Figure III-5 Intrusion of Salinity— Long Term Average

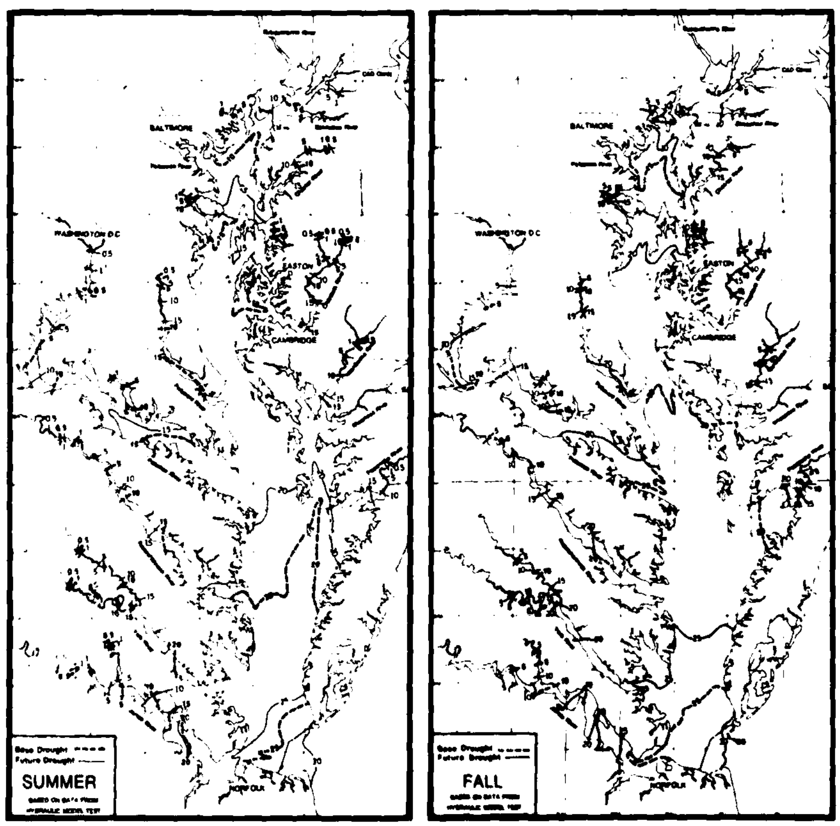


Figure III-6 Intrusion of Salinity— During Drought

Chesapeake Bay have been low and salinities have been high. Along with this had been a rapid increase in MSX related mortalities and a marked intrusion of the disease into new upstream areas.

As shown on Table III-4, the Biota Evaluation Panel has estimated that the population of many of the low salinity varieties of submerged aquatic vegetation will be significantly reduced by decreases in freshwater inflow. These losses are of particular significance. Presently, the population of these species are severely reduced and, according to the findings of the Environmental Protection Agency's Chesapeake Bay Program, rather ambitious programs are needed to restore them. Further declines caused by reduced freshwater inflows could result in the total disappearance of some of the species.

The effects of decreasing freshwater inflows on SAV could be severe even if other conditions were normal. The predicted depressions in the stocks themselves is significant. Added to this is the fact that low salinity SAV is a favored food for many of the waterfowl that cannot be replaced by high salinity SAV. The Biota Evaluation Panel has estimated that redhead ducks would decline 10 to 15 percent under Future Average conditions, and 30 to 40 percent under Base and Future Drought conditions. Other waterfowl that would be adversely affected include the widgeon, pintail, black duck, bufflehead, goldeneye, greater and lesser scaup, ringneck, gadwall and mallard. Scoter, whistling swan and Canada geese could receive some minor benefits from increasing salinities.

The canvasback duck could also be significantly affected by reduced freshwater inflows. Historically it has fed on SAV. Recently it has turned to *Macoma balthica* to supplement its diet. *Macoma,* however, will also decrease markedly (30 percent under Future Average conditions and 45 to 60 percent under Base and Future Drought conditions). The Panel has estimated that this loss in *Macoma* combined with the depression in SAV will result in canvasback duck population declines of 20 percent under Future Average conditions, 30 percent under Base Drought conditions and 50 percent under Future Drought conditions.

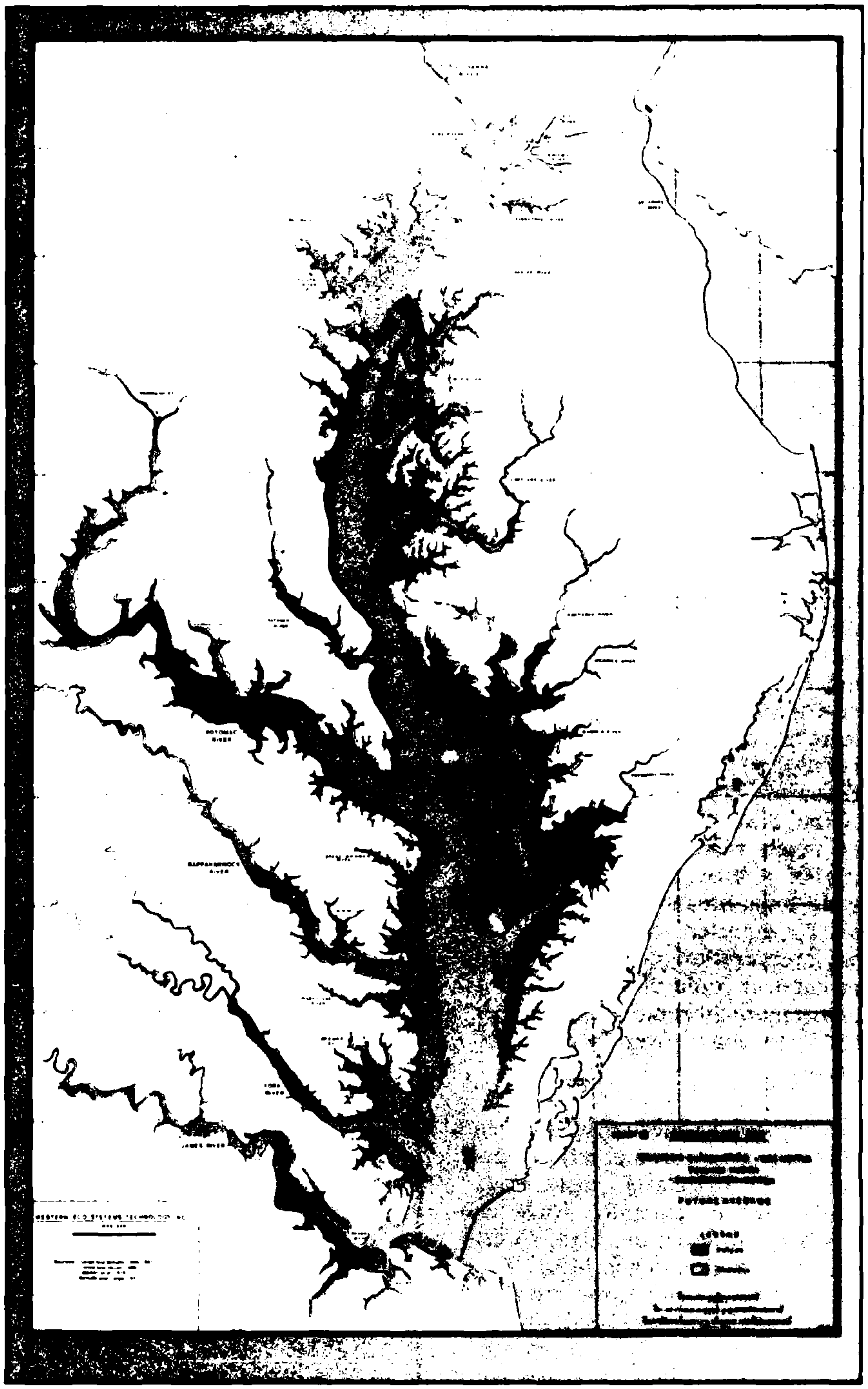


Figure III-7 Sample Habitat Map

TABLE III-1

SUMMARY OF FINDINGS OF THE BIOTA EVALUATION PANEL

In its report, the Biota Evaluation Panel assumed that population change would be proportional to change in potential habitat. Its members concluded that "Intensive consideration of potential effects of reduced input of freshwater into the Chesapeake Bay tidal system emphasized: (1) the complexity of the system and of these effects; (2) the importance of conservatism in permitting such reductions; and (3) the possibility of serious damage to important resources from a combination of continuing withdrawals and natural drought."

"Substantial reduction in freshwater input is estimated to affect representative Bay species and groups in the following ways:"

Highly favored	
Heteromastus filiformis	polychaete worm
Pectinaria gouldii	polychaete worm
Ampelisca abdita	amphipod crustacean
Urosalpinx cinerea	oyster drill
Eupleura caudata	oyster drill
Haplosporidium nelsoni	MSX oyster parasite
Perkinsus marinus	Dermo oyster parasite
Anchoa mitchilli	bay anchovy
Moderately favored	
Chrysaora quinquecirrha	sea nettle
Mnemiopsis leidyi	comb jelly, ctenophore
Streblospio benedicti	polychaete worm
Mulinia lateralis	coot clam
Mercenaria mercenaria	hard clam
Balanus improvisus	barnacle
Crangon septemspinosa	sand shrimp
Leiostomus xanthurus	spot
Brevoortia tyrannus	menhaden
Oceanic fish	
Depletion of oxygen	
Small or mixed effect	
Palaemonetes pugio	grass shrimp
Callinectes sapidus	blue crab
Mesohaline zooplankton	
Mesohaline submerged vegetation	
Mesohaline marshes	
Moderately reduced	
Cyathura polita	isopod crustacean
Morone americana	white perch
Alosa pseudoharengus	alewife
Perca flavescens	yellow perch
Anas americana	widgeon
Anas acuta acuta	pintail
Oligohaline submerged vegetation	
Oligohaline marshes	
Oligohaline zooplankton	
Nutrient input	
Total primary production	
Rates of passive transport	
Significant reduction	
Limnodrilus hoffmeisteri	oligochaete worm
Scolecolepides viridis	polychaete worm
Scottolana canadensis	copepod
Gammarus daiberi	amphipod
Macoma balthica	Baltic macoma
Rangia cuneata	brackish clam

Table III-1 (cont'd)

Crassostrea virginica, adult	**oyster (from predators and parasites)**
Crassostrea virginica, seed	**oyster (from predators)**
Mya arenaria	**soft-shelled clam**
Alosa sapidissima	**shad**
Morone saxatilis	**striped bass**
Aythya valisineria	**canvasback**
Aythya americana	**redhead**
Oligohaline phytoplankton	
Oligohaline zooplankton	

The soft clam is another organism that will decline because of reduced freshwater inflows. During personal communications, Bay area scientists indicated that this species would experience large declines under Future Average and very large declines under the Base and Future Drought conditions.

At an international symposium held in 1958, a system was developed to characterize the estuarine environment. This is called the "Venice System." Under this system, the estuary is divided into zones which generally correspond to the breakpoints in organism distributions. These zones are as follows:

Tidal Freshwater	0.0 to 0.5 ppt
Oligohaline	0.5 to 5.0 ppt
Mesohaline	5.0 to 18.0 ppt
Polyhaline	18.0 to 30.0 ppt
Euhaline	over 30.0 ppt

Salinity is the primary factor that determines the boundaries of these zones. As freshwater inflows decrease and salinity increases these zones move further upstream and in many cases may be compressed in size. This is demonstrated in Table III-5 where the effect of reduced freshwater inflow on the oligohaline and tidal freshwater zones is shown.

The striking reduction in the size of the oligohaline zone is one of the more specific and critical problems caused by reductions in freshwater inflow. The tendency in the estuary is for nutrients and detrital material to concentrate at the interface between salt and freshwater. During spring and summer the low salinity area becomes the site of prodigious growth of phytoplankton and, later, for zooplankton such as the important juvenile fish food *Eurytemora affinis*. Many types of fish use this area, including both anadromous and semi-anadromous species such as striped bass, shad, white and yellow perch and alewife, and ocean spawners, such as menhaden, spot and croaker. Significant species that are dependent on the oligohaline and/or tidal freshwater zones for their existence are listed in Table III-6. Other species, as well as other portions of the life histories of species listed, use the oligohaline zone, but either are not as significantly affected or have major habitat components beyond the low salinity zones. In summary, the role of the oligohaline zone in the line histories of this wide spectrum of organisms, as well as its role in overall ecosystem function, makes imperative its protection and, if possible, enhancement.

Bay Ecosystem. Much of the work on this study focused on the habitat of individual species as defined by salinity, substrate, and water depth. Other issues related to the ecosystem include the interactions between species (e.g., disease, predation, and competition), and other physical and chemical functions (e.g., nutrient budgets, climate, and circulation). Development of an ecosystem model of the essential physical and biological characteristics of the Bay would help in unraveling the significance of these numerous variables. A large obstacle in this is data availability and knowledge of essential linkages and processes. As a substitute, diagrams have been created of the physical and biological interrelationships of major Chesapeake Bay species and communities to aid in identification of possible important ecosystem alterations. In addition, the Biota Evaluation Panel addressed this subject in detail. It was concluded that the net adverse impact on the ecosystem associated with decreasing freshwater inflow would be small under the Future Average conditions, moderate under the Base Drought and moderate to large under the Future Drought.

Aesthetics. Chesapeake Bay is well known for its aesthetic values. Many hours are spent by the thousands of people enjoying the reflection of the sun and moon on its waters, watching the waterfowl in their mass migrations and in just quiet solitude. The reductions in

TABLE III-2

SUMMARY OF ENVIRONMENTAL IMPACTS

Environmental Category Account	Impact Criteria	Magnitude of Adverse Impacts: Future Average	Base Drought	Future Drought	Extent of Effects: Local	Regional	National
AQUATIC RESOURCES							
•Tidal Fresh Phyto.	Habitat loss	—	VL	VL	X		
•Mesohaline Phyto.	Habitat loss	M	L	L	X		
•*Proprocentrum minimum*	Habitat loss	—	M	L	X		
•*Ceratophyllum demersum* & other low salinity SAV	Habitat loss	S	L	L	X	X	
•Tidal Fresh Marsh	Habitat loss	S	M	L	X		
•*Brachionus calcyiflorus*	Hatibat loss	—	L	L	X		
•*Eurytemora affinis*	Habitat loss	—	L	L	X		
•*Scottolana Canadensis*	Habitat loss	—	VL	VL	X		
•*Bosmina longirostris*	Habitat loss	—	VL	VL	X		
•*Limnodrilus hoffmeisteri*	Habitat loss	—	L	VL	X		
•Oyster (MSX & Dermo.)	Habitat loss	L	VL	VL	X	X	X
•*Macoma balthica*	Habitat loss	M	L	L	X		
•Soft Clam	Habitat loss	L	VL	VL	X		
•Shad	Habitat loss	—	M	L	X	X	X
•Alewife	Habitat loss	—	M	M	X		
•White perch	Habitat loss	—	M	M	X		
•Striped bass	Habitat loss	—	M	L	X	X	X
•Yellow perch	Habitat loss	M	M	M	X		
•Canvas back	Habitat loss	M	L	L	X	X	X
ECOSYSTEM	Net adverse effect	S	M	M-L	X	X	X
AESTHETICS							
•Water quality	Flushing in subestuaries	—	M	M	X		
•Canvas back	Number of ducks	—	S	S	X		
•Boat-docking facilities	Collapsing boat docks	S	M	M	X		
•Sea nettle	Effect on recreationists	S	S	X			
RARE AND ENDANGERED SPECIES	Habitat loss	—	M	M	X	X	X

LEGEND
- — Insignificant
- S Small
- M Medium
- L Large
- VL Very Large

TABLE III-3

LOSS IN OYSTER POPULATION
DUE TO PREDATORS AND DISEASE

Freshwater Inflow Condition	Maryland	Virgina	Bay-Wide
Future Average	50%	0%	30%
Base Drought	90%	20%	65%
Future Drought	100%	50%	80%

freshwater inflow caused by consumptive losses of water or droughts is not expected to markedly change these experiences. There are, however, four factors that could contribute to a small to moderate intrusion on the aesthetic experience. These are, a degrading of water quality, a loss in the numbers of waterfowl, an increase in the density of sea nettles and a degradation of boating docks by wood borers.

Water Quality. A small degradation of water quality conditions could be caused by reduced freshwater inflow; especially near wastewater discharges. Here, there may be an increase in odors and a loss of some visual amenities through algae blooms, scum or other factors. These losses will probably be insignificant under Future Average conditions. During a drought, the loss in aesthetic values due to water quality degradation would be at the most, moderate.

Waterfowl. Many people enjoy watching the many varieties of waterfowl that either permanently live in the Chesapeake Bay area or are temporary visitors during winter. The population of some of these waterfowl, such as the redhead and canvasback duck, have markedly declined in recent years. This is partly related to the nearly total disappearance of submerged aquatic vegetation, their historically favored food. Changes in freshwater inflow could further reduce this vegetation or prevent its re-establishment. This could cause a further decrease in waterfowl populations.

Sea Nettles. Aesthetics would be adversely affected by an increase in sea nettles. The increased habitat for sea nettles is small (only 12 percent in the Future Drought) but increased densities, due to better reproductive success, could result in undesirable densities.

Boat Docking Facilities. The potential for the *Bankia* and *Teredo* to expand their range and attack boating facilities could adversely affect the visual experience. Considering the 12,000 additional slips affected in the Base Drought, and 18,000 additional slips in the Future Drought, the destruction along the shores of the Bay's valued boating waters could be significant. Future Average impacts would be small at most.

TABLE III-4 *REDUCTIONS IN LOW SALINITY SAV*

Species	*Future Average*	*Base Drought*	*Future Drought*
Ceratophyllum	—	40%	40%
Zannichellia	20%	40%	40%
Potamogeton Spp.	20%	40%	40%
Vallisneria	20%	40%	40%
Myriophyllum	20%	40%	40%
Chara	20%	40%	40%

TABLE III-5 *REDUCTION IN OLIGOHALINE AND TIDAL FRESHWATER ZONES*[1]

Salinity Zone	*Future Average*	*Base Drought*	*Future Drought*
Oligchaline	21%	59%	77%
Tidal Freshwater	unchanged	36%	51%

[1]Benchmark is habitat under Base Average Conditions.

TABLE III-6 *SPECIES DEPENDENT ON TIDAL FRESHWATER AND OLIGOHALINE ZONES*

Phytoplankton
Tidal Freshwater Assoc.
Oligo/low meso. Assoc.
Ceratophyllum demersum (SAV)
Tidal freshwater marsh assoc.
Brachionus calcyiflorus (rotifer)
Eurytemora affinis (copepod)
Scottolana canadensis (copepod)
Bosmina longirostris (cladoceran)
Limnodrilus hoffmeisteri (Oligochaete worm)
Scolecolepides Viridis (polychaete worm)
Cyathura polita (isopod)
Gammarus daiberi (amphipod)
Alosa sapidissima (Am. shad)
Alosa pseudoharengus (alewife)
Morone saxatilis (striped bass)
Morone Americana (white perch)
Perca flavescens (yellow perch)

Rare and Endangered Species. Thirteen federally listed endangered species live in the Bay area. Included are one fish (the shortnose sturgeon), five sea turtles, one bird (bald eagle) and six whales. None of these is expected to be affected by reduced freshwater inflows. However, several species of rare plants live in the tidal areas of the Bay and may be affected by increased salinity levels. The species most likely to be seriously impacted is the joint vetch *(Aeschynomem virginica)*, since it is only found in Maryland at two locations on the lower Eastern Shore. Under Future Drought conditions, it is possible that salinities would be high enough to reduce the limited populations. The marsh alder, *Alnus maritima*, could be adversely affected in the Nanticoke River. Other populations do exist in the headwaters which presumably would not be impacted. Similarly, the distribution of three other rare species is limited to the Susquehanna flats. Lethal levels of salt are not expected in this area under any of the flow conditions.

Economic Resources

Most of the adverse economic impacts associated with reductions in freshwater inflow will be on the commercial fishing industry, recreation, and the municipalities and industries that use the Bay as a source of water supply. Economic impacts are displayed by category, magnitude of impact, and predicted scope of importance (local, regional, national) in Table III-7. The degree of adverse impact is measured against the Base Average economic value for each resource.

TABLE III-7

SUMMARY OF ENVIRONMENTAL IMPACTS

Economic Category Account	*Impact Criteria*	*Magnitude of Adverse Impacts* *Future Average*	*Base Drought*	*Future Drought*	*Extent of Effects* *Local*	*Regional*	*National*
COMMERCIAL FISHERIES							
•Oyster	Lost harvest values	L	L	VL	X	X	X
•Striped Bass	Lost harvest values	S	M	L	X	X	
•Shad	Lost harvest values	S	M	L	X	X	
•Soft Clam	Lost harvest values	L	VL	VL	X	X	
RECREATION							
•Swimming (Sea Nettle)	Reduced expenditures	—	—	—	X		
•Boating *(Teredo & Bankia)*	Reduced expenditures	M	EX	EX	X	X	
•Waterfowl Hunting (Canvasback and other ducks)	Reduced expenditures	—	S	S	X	X	
•Sportfishing	Reduced expenditures	—	—	—	X	X	
BAY WATER USERS							
•Municipal costs	Increased treatment	—	—	—	X		
•Industrial	Increased treatment	—	—	—	X		
•Power	Increased treatment	—	—	—	X		

LEGEND
- — Insignificant
- S Small
- M Medium
- L Large
- VL Very Large
- EX Extreme

Commercial Fishing. The average commercial fishing harvest in the Chesapeake Bay during the period 1952 to 1980 totaled 298 million pounds and was worth an average of $73 million. Included were oysters, clams, crabs, menhaden, shad, spot, striped bass, and bluefish. Oysters had the largest value comprising nearly 47 percent of the total. Blue crabs, menhaden, soft clams and striped bass respectively made up 20, 18, 7 and 4 percent of the value of the catch.

Future Average freshwater inflow conditions could cause an annual average reduction in total harvest of approximately 10 million pounds, worth $15.2 million dockside. Oysters and soft clams account for 99 percent of this dollar loss. Of the Bay's important commercial finfish species, only striped bass and shad were affected. Each would be reduced approximately 5 percent over the Base Average. However, these impacts probably would not be discernible from natural population variations according to Bay fisheries experts. Also, the levels of confidence are less for the finfish estimates than for the benthic type organisms such as oysters and soft clams. Based on this, oysters and soft clams are felt to be the only species warranting specific formulation for economic objectives under Future Average conditions.

The drought events cause more dramatic effects on commercial fisheries then the Future Average. Total dockside value losses during the duration of the events range from $156 million in the Base Drought to $334 million in the Future Drought. Again, oysters are the most severely impacted, losing an estimated $120 million under Base Drought conditions and $280 million under the Future Drought. Soft clam losses are an estimated $23 million due to the Base Drought event and $26 million due to Future Drought. Together, the shellfish account for about 95 percent of the total commerical fishery economic impact of both drought events. Because these shellfish are immobile, there is a relatively high degree of confidence in these estimates. Oysters and soft clams were of prime importance in formulation of freshwater inflows criteria for Chesapeake Bay.

There is less confidence in the estimates for striped bass and shad. This is due to the lack of knowledge about the relationships between salinity, habitat and fish stock size. Also, the significance of the impact would depend on the health of the stocks of adult fish prior to the drought event. For these reasons, impacts were estimated in a range. The losses in the catch of shad range from $0.9 to $3.2 million for the Base Drought and $1.2 to $8.6 million for the Future Drought. Likewise, the losses of striped bass range from $0.5 to $6.5 million for the Base Drought and $0.6 to $13.9 million for the Future Drought. These impacts are equivalent to approximately 5 to 7 percent of the total commerical fishery economic impact. In summary, it is doubtful whether management of salinity in Chesapeake Bay for benefit of commercial finfish harvest could be economically justified. All of the above discussion concerning drought conditions assumes healthy stocks of adult fish are present at the beginning of an event. Low stocks would make the need for protection of spawning and nursery areas much more critical if damage to an already weakened base population is to be avoided. In summary, oysters and soft clams appear to warrant particular attention due to their commercial importance and potential high degree of impact.

Recreation. Changes in the habitat of several Chesapeake Bay species will affect man's recreation activity, and, in turn, cause direct and indirect economic impacts. Of particular concern are boating, swimming, sportfishing, and waterfowl hunting.

Boating. Rises in maintenance costs to boat owners and marina operators will accompany the projected increases in the distribution of shipworms and barnacles. The amount of economic loss depends on the degree, type, and condition of borer-resistant treatments on existing marina pilings. Under Future Average freshwater inflow conditions, the number of boating slips potentially affected by shipworm will increase by about 15 percent. This is approximately 1600 slips.

Base Drought conditions could cause infestation of nearly 12,000 additional slips (a 120 percent increase), while 18,000 more slips would be affected under Future Drought conditions than Base Average ones. This large increase is due to the borers moving into and beyond the boating concentration at Annapolis, Maryland. Although drought events are a temporary phenomena, the ability of these borers to move rapidly into new habitats highlight the possible economic significance of these types of conditions.

The only other organism of concern to the boating public is barnacles. Base Drought salinities increase the number of slips potentially affected by only 9 percent, which is the worst case. Future Average conditions increase the number of slips affected by less than 1 percent. Future Drought conditions actually cause a 1 percent *reduction* in the number of slips affected by the barnacles. The resulting economic effects are not expected to be significant.

Swimming. While sea nettles are a significant detractant to swimming opportunity and enjoyment in Chesapeake Bay, the increase in the miles of beach affected from 154 to 175 is not felt to represent a significant economic impact. Visitation and expenditure information for Bay beaches are not available, and the relationship between these variables and sea nettle infestation is a further unknown. The increased densities of infestation that could occur in areas presently infested by sea nettles may be a bigger problem than expanded range. Even in this case, there are methods available to screen sea nettles away from important beach-front areas.

Sportfishing. Sportfishing is a major recreation activity in Chesapeake Bay. Through its many support facilities and services, it is estimated to have contributed $507 million to the regional economy in 1979. It was not possible to identify or compute the economic impact that would result from decreases in freshwater inflow. It is true that favored fish such as the striped bass and shad may be somewhat reduced. In fact, the stocks of these fish are already low. But, a review of the records reveals that there apparently has not been a large reduction in the fishing effort. Rather, many of the sport fisherpersons have turned their attention to fish of marine origin such as the blue and weakfish. If these records are a valid indication of trends, there probably would be little or no change in the sportfishing revenue resulting from reductions in freshwater inflows.

Waterfowl Hunting. The waterfowl most affected by reduced freshwater inflow are canvasback, redhead, pintail, and widgeon. This is because of their dependence for food on either the low salinity varieties of submerged aquatic vegetation (SAV), or, as is the case for canvasback, the clam *Macoma balthica.* The populations of these waterfowl, along with many other more omnivorous species, were depressed in the 1970's due to the Bay's marked decline in SAV. While the estimated overall value to the State of Maryland of waterfowl hunting activity is estimated at between $10 and $20 million, the next change that may occur due to reduced freshwater inflows is unknown. This is due to the many and indirect natures of cause and effect. Despite this lack of quantifiable impact, it is important to maintain the appropriate habitats for low-salinity of SAV and *Macoma* as vital food for economically important waterfowl.

Bay Water Users. Increases in salinity in the Bay can affect the municipalities and industries that use the estuary as a water supply source. One affected municipal system is Havre de Grace, Maryland. Based on the assumed treatment costs, the system would expend as much as $2.0 million per year in order to overcome the salinities expected with the Base Drought condition, and $6.7 million with the Future Drought. Similarly, the water supply system at Hopewell, Virginia, could sustain $4.9 million per year losses with Future Drought salinities. Because of these possible costs, it is likely that new water sources or protective measures to preclude saline intrusion will be adopted by the water supply authorities.

Salinity increases are not considered a problem by the industries located in the Bay Region. Ninety percent of the projected $36.5 million increase in expenditures to combat salinities in the Future Drought conditions is due to 16 proposed new power plants on Bay tidal waters. Based on interviews with power company experts, it is felt that the costs, even for the Future Drought condition, will be of minor significance since the plants will be designed for saline water use.

Social Resources

Changing abundances of Bay organisms can cause impacts other than economic and environmental. Among

TABLE III-8

SUMMARY OF SOCIAL IMPACTS

Social Category Account	*Impact Criteria*	*Magnitude of Adverse Impacts* *Future Average*	*Base Drought*	*Future Drought*	*Extent of Effects* *Local*	*Regional*	*National*
HEALTH & SAFETY							
•Sea nettle	Effect on swimmers	—	—	S	X		
•Public water systems	Effect of salt on public health	—	—	—	X		
RECREATION EXPERIENCE							
•Sportfishing	loss of preferred species	—	S	M	X	X	
•Waterfowl hunting	Population loss of favored waterfowl	S	M	L	X	X	
•Swimming and waterskiing	Increased densities loss sea nettle	—	M	M	X		
•Boating	Effect of borers	—	S	S	X	X	
TRADITIONS							
•Ches Bay watermen	Loss of oysters	M	L	VL	X	X	X

LEGEND
- — Insignificant
- S Small
- M Medium
- L Large
- VL Very Large

these are health and safety, special traditions, science and education, and such ethereal things as recreation experience. Of these, only recreation and traditions are felt to have significance in planning for low freshwater inflow. A summary of the effects of decreased freshwater inflow on these social resources is shown on Table III-8.

Swimming and Water Skiing. Moderate impacts would be sustained by swimmers and water skiers in their increased encounters with sea nettles, especially during droughts. Increased densities are felt to be potentially more troublesome than increases in ranges. Future Average impacts would be essentially indistinguishable from the present. Base and Future Droughts have the greatest potential for impacting on the swimming experience. While sea nettles cause only painful stinging sensations to most victims, health risks may also be involved for persons who experience allergic reactions.

Sportfishing. Although current sport fishing favorites include ocean species such as bluefish and weakfish, a highly important tradition surrounds the fishery for shad and striped bass. In a manner of reasoning, the public's historical participation in fishing for striped bass and shad can be considered important elements of the public's (especially the fisherman's) concept of the Bay itself. That Chesapeake Bay is a great provider of fish and shellfish is understood by a majority of Bay area residents. An injury or loss of a prominent and well known species, such as shad or striped bass, would be both a loss of the potential for recreation and an injury to people's concept of the Bay. Conversely, enhancement of these presently threatened species would contribute significantly toward attainment of the concept of a healthy and productive Bay. The effects of increases in salinity on the sportfishing experience is expected to be insignificant in the Future Average and moderate in the Base and Future Drought events.

Sport hunting. Impacts on Chesapeake Bay duck populations due to the potential reductions in their food sources could be significant. Canvasback ducks were a major hunting activity before their abrupt decline put them on protected lists in Maryland and Virginia. These ducks would be hurt by losses to *Macoma balthica* and submerged aquatic vegetation. Future Average reductions of 20 percent would constitute a moderately significant impact on the ducks themselves, as well as to Bay recreation experience. During Base Drought conditions, canvasback ducks could be reduced by 30 percent. Future Drought event could reduce them 50 percent.

Other important Bay waterfowl such as the redhead, pintail and widgeon, depend for their food on submerged aquatic vegetation such as *Potamogeton* spp. (pondweeds), wildcelery, *Zannichellia, Ceratophyllum,* and eelgrass *(Zostera)*. All but the last of these live in areas where salinities are less than 15 ppt. Potential impacts to the plant eating ducks would be most significant during the drought events since the low-salinity varieties will be reduced.

The significant present state of decline in Bay SAV and their evident importance to the species mentioned above (among numerous other unmentioned species) indicates a need for SAV protection or, if possible, enhancement.

Traditions. The activities of Chesapeake Bay watermen, convey to many an im-

age of skipjacks sailing for oysters in winter, and manning the trotline for crabs in summer. The grizzled veterans that carry on these activities are part of a tradition that dates from the Bay's first settlement. Some Bay communities have changed little since their founding over 300 years ago. Loss of traditional harvesting grounds, especially for a species such as the all-important oyster, would encourage a decline in the waterman and his unique way of life. The importance of finfish in the waterman's way of life is less easily quantified, and probably at the same time less critical. Using oysters as the principal barometer, traditions associated with commerical fishing in Chesapeake Bay could be very significantly affected.

Priority Problems

In the previous section, the effects of reduced freshwater inflows on aquatic plants and animals has been evaluated from environmental, economic and social perspectives. It is clear that many of the species that live in Chesapeake Bay will be seriously adversely affected and that significant socio-economic and environmental damages will occur. Specific plans should be developed to eliminate, reduce or mitigate these damages. A list of these species is shown in Table III-9.

Of particular importance are the oysters and those species that depend on the oligohaline and tidal freshwater zones. Nearly equally important are the low salinity SAV, soft clam and *Macoma*. Plan formulation efforts focused primarily on these species. The sea nettle, *Teredo* and *Bankia* are also important, but certainly not as important as the other species. These organisms, however, were included in the initial stages of the plan formulation effort.

The municipalities and industries that use the Chesapeake Bay and its estuarine tributaries as a water supply source would not be seriously damaged by decreases in freshwater inflow. In addition, the municipalities and most industries are already taking the measures necessary to cope with potential increases in salinity. Therefore, formulation of specific plans for water users was not warranted.

TABLE III-9

PRIORITY PROBLEM SPECIES

1. Oyster (including drills and MSX)
2. Oligohaline/Tidal Freshwater Zone
   - Phytoplankton
     - Tidal Freshwater Assoc.
     - Oligo/low meso. Assoc.
   - *Ceratophyllum demersum* (SAV)
   - Tidal freshwater marsh assoc.
   - *Brachionus calcyiflorus* (rotifer)
   - *Eurytemora affinis* (copepod)
   - *Scottolana canadensis* (copepod)
   - *Bosmina longirostris* (cladoceran)
   - *Limnodrilus hoffmeisteri* (Oligochaete worm)
   - *Scolecolepides Viridis* (polychaete worm)
   - *Cyathura polita* (isopod)
   - *Gammarus daiberi* (amphipod)
   - *Alosa sapidissima* (Am. shad)
   - *Alosa pseudoharengus* (alewife)
   - *Morone saxatilis* (striped bass)
   - *Morone Americana* (white perch)
   - *Perca flavescens* (yellow perch)
3. Low Salinity SAV
4. Sea Nettle
5. Soft Clam
6. *Teredo/Bankia*
7. *Macoma balthica* and Canvasback Duck

Plan Formulation

Federal Objective

Guidelines for the formulation and evaluation of plans for improvement for all Federal water and related resource activities are contained in the *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies,* March 1983. As stated therein, "The single Federal objective of water and related land resource planning is to contribute to National economic development consistent with protecting the Nation's environment, pursuant to National environmental statutes, applicable executive orders, and other Federal planning requirements."

Planning Objectives

The primary objective of the Chesapeake Bay Low Freshwater Inflow Study is to formulate those alternative freshwater inflow related actions which would lead to the preservation or enhancement of the socio-economic and environmental values of Chesapeake Bay and the estuarine portion of its tributaries. Within this very broad objective, more specific guidelines have been adopted through interactions with the scientific community and the public to further define the planning, setting and the subsequent constraints on plan formulation. These objectives provide a focus for development of plans to protect highly valued habitats or otherwise alleviate the short and long-term effects of drought and consumptive losses. They are specific to individual aquatic resources in Chesapeake Bay and are as follows:

1. Protect productive oyster beds from incursions of disease organisms and predators, or otherwise alleviate these damages, for purposes of long-term commercial fishery productivity and Bay traditions.

2. Maintain the size of tidal freshwater and oligohaline salinity zones for their value in ecosystem functions and as a spawning and nursery area for numerous commercially and recreationally important species such as striped bass, shad, spot, menhaden, and alewife.

3. Maintain and/or enhance the productivity of striped bass and shad which are important in commerical harvests, recreation and Bay traditions.

4. Contribute to the propogation of submerged aquatic vegetation for benefit of waterfowl (important components of recreational hunting and Bay traditions) and ecosystem processes.

5. Contribute to the productivity of the clam, *Macoma balthica,* as an essential food for canvasback duck (an important component of recreational hunting and Bay traditions).

6. Contribute to the productivity of the soft clam, *Mya arenaria,* for its commercial harvest values.

7. Reduce the potential for incursion of wood bores *Bankia* and *Teredo* to avoid economic losses at boating harbors.

8. Moderate the proliferation of sea nettles to contribute to water contact recreation experience and aesthetic environmental values.

Constraints and Assumptions

Based on the recommendations of the Biota Evaluation Panel, certain guidelines and procedures were adopted for use in guiding the planning process. These were:

1. Pursue a highly conservative policy toward alterations in the quantity of freshwater inflow, recognizing the high biological value of Chesapeake Bay and acknowledging the limits of predictive capability.

2. Retain the fundamental seasonal freshwater inflow pattern of low flows in the fall and high flows in the spring.

3. Recognize that upstream shifts of species will frequently move them into lower valued habitat.

Major assumptions made in plan formulation include:

1. The use of salinity tolerance alone, in conjunction with knowledge of the habitat variables substrate and depth, is sufficient to permit meaningful alternative plan development and evaluation.

2. The selected "study species" provide a sufficiently adequate representation of all Bay biota to permit the formulation of generalized problem solutions.

3. By the year 2020, the goals of the 1976 Amendments to the Water Pollution Control Act would be met. Therefore, water quality other than salinity would not be a plan evaluation variable.

Plan Formulation Process

A flow chart of the Low Freshwater Inflow Study plan formulation process is shown on Figure IV-1. It started with an identification of those alternative measures that appeared to have application in solving low freshwater inflow related problems and culminated in a display of the most promising alternative solutions.

Two broad categories of measures were considered, i.e., flow supplementation alternatives and Chesapeake Bay alternatives. Flow supplementation alternatives are measures which can be employed in the Bay's tributary drainage basins to provide increased freshwater inflow. Included in this category are conservation of reservoirs, importation of water from other basins, developments of groundwater and growth restrictions. The Chesapeake Bay alternatives include such non-flow supplementation measures as salinity barriers, oyster bed restoration, fisheries management and SAV reestablishment.

At the present time, the state of the art knowledge of detailed applications of the Chesapeake Bay type alternatives is limited. Therefore, only one level of screening was done for them. This screening was oriented to eliminating those measures which obviously were not technically or institutionally feasible at the present time. Further refinement of these Chesapeake Bay alternatives was beyond the scope of this report. Growth restrictions were also subjected to only one level of screening. This was due to the fact that it was not possible to sort out one plan out of the many available combinations.

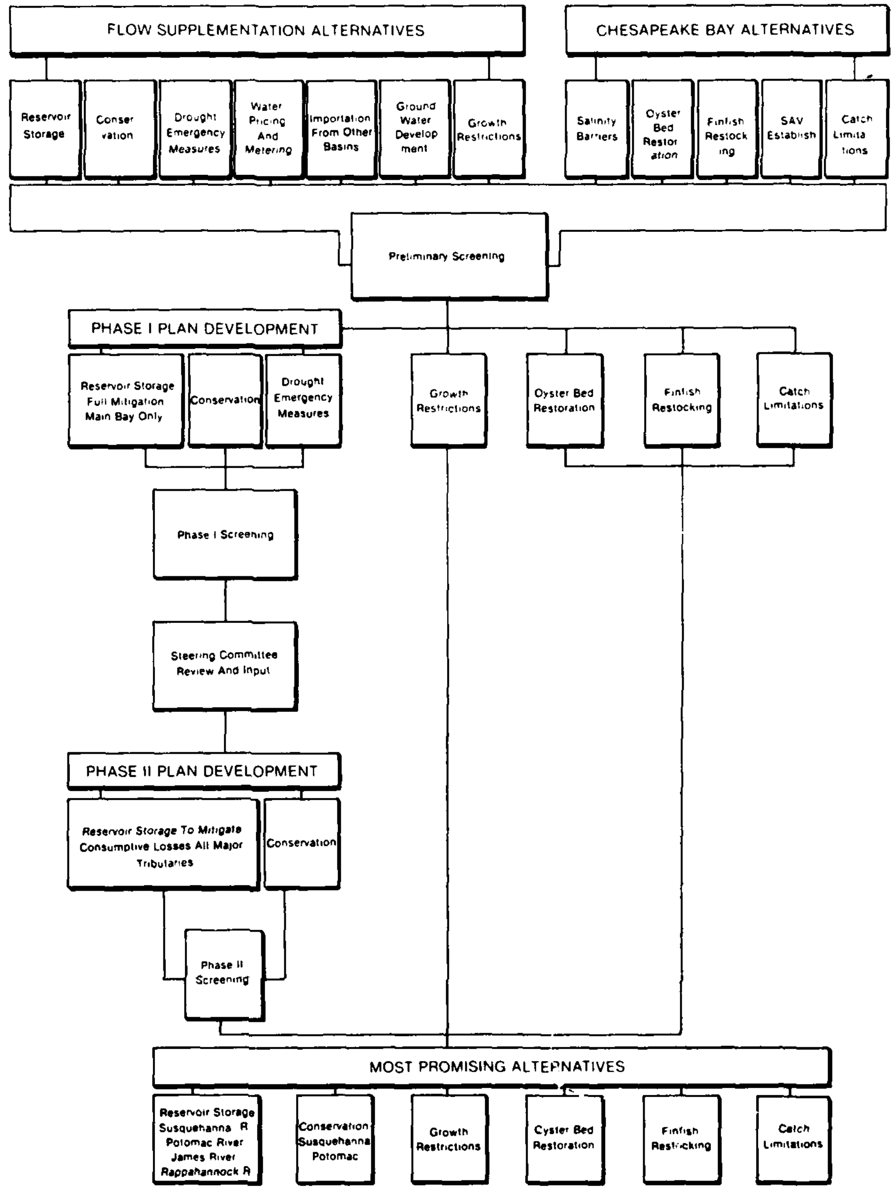


Figure IV-1 Plan Formulation Process

The remaining flow supplementation alternatives were subjected to three levels of development and screening. The preliminary screening was oriented to eliminating from further consideration those measures which obviously were not technically or institutionally feasible. Phase I plan development focused on only the "Main Bay" and the Susquehanna River Basin. Its purpose was to identify the portion of the problem that could be solved through reservoir storage and conservation.

In Phase II, all major tributaries to Chesapeake Bay were addressed. Plans for each problem plant or animal species were formulated for each season of the year and for multiple seasons. These plans were evaluated in detail. Those which appeared to be the most feasible from technical and institutional viewpoints were retained as most promising alternatives.

Preliminary Screening

Flow Supplementation Measures

Conservation. Conservation measures normally reduce the amounts of water needed for water supply for communities, farms and industries. In some cases this will reduce the amount of water that is used consumptively, although a few conservation measures such as recirculating cooling processes can actually increase consumptive losses.

Conservation can take many forms. In the public, domestic, commercial sector

it usually takes the form of water saving fixtures such as shower heads, washing machines, etc. In manufacturing, it often consists of changes in processes that result in saving water. Once installed, they are considered permanent and normally save water year around.

Three levels of water savings through conservation were investigated. The medium level was considered the most reasonable and cost effective. Although the savings in consumptive losses produced by conservation were small, it was retained for further consideration.

Drought Emergency Measures. These measures normally consist of actions taken during a water shortage to temporarily reduce the amount of water being used. They often include bans on such activities as lawn sprinkling or the washing of automobiles. Although the savings in consumptive losses associated with these measures are small, they were retained for further consideration in the plan formulation process.

Upstream Storage. Upstream water storage would be provided through the construction of dam and lake projects in the tributary drainage basins to Chesapeake Bay. Water would be stored during periods of surplus stream flows for release during low flow periods. Upstream storage is well proven in its potential for supplementing stream flow and therefore was retained for further investigation during plan formuation.

Interbasin Importation of Water. The importation of water into the Chesapeake Bay area from other drainage basins was considered only briefly. It was eliminated from further consideration in light of high cost, potential adverse socio-economic and environmental impacts in other basins, and potential implementation difficulties.

Groundwater Development. Large scale groundwater development could be used to supplement the freshwater inflows to Chesapeake Bay. This measure was also dropped due to potential high cost and the likely adverse impact of large withdrawals on local groundwater users.

Pricing and Metering. Pricing and metering are water use control devices that are based on the concept of elasticity of demand. It is hypothesized under this concept that water demands would decrease as the price of water increases.

In order to implement this type of measure, it would be necessary to install meters in every home, commercial establishment and industry to monitor water use. Rates would be set at levels high enough to discourage all but essential uses. But, the few studies available on the effectiveness of pricing and metering indicate that domestic and commercial water use is price inelastic. This is due to a combination of factors relating to the basic necessity for water and public affluence. Also, it was found that the potential is small for reducing consumptive losses of water in industrial related activities. In view of this, water pricing and metering were dropped from further consideration.

Growth Restrictions. The amount of consumptive losses that occur in a particular water shed could be reduced by adopting regional development policies or laws. Under this concept, population or industrial growth would be regulated in order to keep water demands and associated consumptive losses within predeterminded boundaries. Also, specific types of water use such as irrigation or evaporation cooling processes could be forbidden or controlled.

The quantities of water that could be saved would be a function of the amount and type of water used. Due to the many combinations that could occur, specific plans for restricted growth were not formulated. However, the concept of growth restriction was retained as a most promising alternative.

Chesapeake Bay Measures

The second of the two major types of measures, "Chesapeake Bay" measures, are actions which can be employed within the more immediate tidal Chesapeake to solve low-flow related problems. These include structural and resource management options such as oyster bed restoration, fisheries management, SAV reestablishment, and salinity barriers.

Salinity Barriers. Salinity barriers, in the form of solid structures constructed across a portion of the Bay or one of the subestuaries, could effectively prohibit the intrusion of high salinity waters. While effective in reducing salt water intrusion, potential negative effects include: (1) reducing the normal flushing action of a subestuary, (2) interrupting the normal migratory movements of various species of finfish, and (3) disrupting commercial and recreational boating. Further, a detailed analysis of barrier plans would probably require model testing. Thus, due to the high degree of adverse impact and inability for additional model testing, salinity barriers were dropped from further consideration.

Fisheries Management. Given the importance of commercial and sportfishing to the Chesapeake Bay Region it is not surprising that the involved states all have comprehensive fisheries programs and attendant research and resource study programs. The alternative to be considered is modifying the existing programs of the states in order to be more responsive to the problems/needs identified in the Low Freshwater Inflow Study. Given the problem species and areas, the state resource agencies will be better able to target catch restrictions, minimum length requirements, hatchery programs and other measures to aid those commercially and recreationally important fin and shellfishes that are adversely impacted by low flows. Although the present relationship of fishery management measures to fish populations in the estuary are largely unproven or unknown, there have been some apparent successes attributed to catch restrictions and finfish restocking. Due to this, and the potential for these measures to help alleviate drought and long term average problems, catch restriction and finfish restocking were retained for consideration as most promising alternatives.

SAV Reestablishment. Submerged aquatic vegetation are currently substantially reduced in Chesapeake Bay. Programs have been initiated sporatically in attempts to reestablished beds that have been lost, but success has been irregular. Reasons for the SAV decline are largely unknown, although the EPA Chesapeake Bay Program has identified likely candidates, including a basic change in the hierarchy of aquatic systems due to nutrient enrichment. With unknowns and variables of the magnitude identified in the EPA study, the potential for meaningful reestablishment of SAV is presently unknown. Also, past attempts at SAV bed reestablishment have proved largely unsuccessful. Thus, SAV reestablishment was not considered further.

Oyster Bed Restoration. Oyster bed restoration is a process of transferring young or seed oysters as well as shell into low production or depleted oyster beds. Here they are allowed to grow to maturity for harvest two to three years later. Oyster bed restoration has largely been credited with helping to sustain the State of Maryland's oyster production since 1960. The Commonwealth of Virginia has a similar long-established and successful program. This apparent success indicates that this measure may be a variable means of offsetting losses in oyster productivity due to low freshwater inflows and increased diseased mortality.

Formulation of Flow Supplementation Plans

Conservation

The potential for accumulation of large benefits through the institution of conservation measures is small. This may be surprising in view of the large reductions in water demands that often result from conservation. For the most part however, conservation measures that are presently used are more oriented to reducing water demands than consumptive losses. This is reflected on Table IV-1 where potential savings in consumptive losses through both permanent conservation measures and emergency drought measures are compared with year 2020 consumptive losses. The many blank spaces on this table indicate that the savings in a particular river basin are less than one mgd.

Implementation of conservation plans would be very difficult and costly in an area as large and diverse as the Chesapeake Bay Basin. Because communities and industries are, for the most part, already established, large amounts of replumbing, retrofitting and perhaps changes in manufacturing processes may be required. Also, the responsibility for instituting these measures would rest with the hundreds of local political subdivisions.

In view of these factors, there is some question whether the benefits associated with conservation measures are sufficient to justify their costs. But, conservation is the only feasible measure that would decrease long term average consumptive losses. Also, conservation does have recognized benefits beyond those resulting from reductions in consumptive losses. In view of these factors, it was decided to retain for further analyses in Phase II, conservation measures in only those river basins where average annual reductions in consumptive losses are 10 percent or greater. These basins are the:

Susquehanna River Basin
Potomac River Basin
York River Basin
Rappahannock River Basin
Patuxent River Basin
Chester River Basin
Choptank River Basin

TABLE IV-1

CONSERVATION POTENTIALS

POINT	*BASIN*	*Year 2020 Consumptive Losses (mgd)*	*Potential Medium Conservation (mgd)*	*Drought Emergency Measures (mgd)*
15	Susquehanna	992	178	54
1	Nansemond	105	2	7
2	Chickahominy	4	—*	—
3	Appomattox	25	—	—
4	James	226	4	15
5	York	98	14	5
6	Rappahannock	50	5	4
11	Patuxent	14	2	1
12	Severn	13	—	—
13 & 14	Upper Western Shore	389	27	25
16	Bohemia	14	—	—
17	Chester	30	6	3
18	Wye	0	—	—
19	Choptank	72	17	5
20	Nanticoke	34	2	2
21	Pocomoke	18	—	—
7	Lower Potomac	6	—	—
8	Occoquan	9	—	—
9	Anacostia	2	—	—
10	Potomac (D.C. and Above)	472	50	35

*—Conservation is Less Than 1 MGD

Reasonable Storage

The initital step in the storage analysis was to develop an inventory of those existing Federal and non-Federal projects that have a total storage in excess of 10,000 acre-feet. It was at first assumed that up to 50 percent of the conservation storage that was not already committed for low flow augmentation storage could be allocated for releases for the Bay. It was further assumed that any flood control storage above three inches could also be reallocated for low flow augmentation. While reallocation for this purpose would be beneficial, there would likely be major adverse recreation and fish and wildlife impacts within the reservoir areas of most of the projects. Further, the loss of flood control storage would likely be perceived as a major adverse impact even if the loss of benefits is minor. After consideration of the various reallocation assumptions, it was decided that a practicable reallocation level would be 20 percent of the present conservation storage. Further, no flood control storage would be reallocated for low flow purposes.

Consideration was also given to the construction of new storage projects. The potential projects initially identified included those Federal and non-Federal projects that were under construction, authorized, recommended for construction, or found to have merit in recent comprehensive basin studies. This initial inventory was then screened and those projects which appeared to have the most merit were selected and the total storage was summed for each of the major basins. Only reservoir sites in the Susquehanna, Potomac, James and Rappahannock Rivers were retained.

One other factor was considered in the development of reservoir storage criteria. One of the plan formulation

goals is the retention of the natural seasonal patterns of freshwater inflow to Chesapeake Bay. In order to assure achievement of this goal, storage in each basin was limited to 5 percent of the average annual discharge of the river or stream. Thus, the reasonable upper limit of reservoir storage considered in plan formulation was a function of either the availability of reservoir sites or the limits to flow modification. Shown on Table IV-2 are potential upstream storages for each major basin. The lower of the values are those considered reasonable. These are marked with an asterisk.

TABLE IV-2

POTENTIAL REASONABLE UPSTREAM STORAGE CHESAPEAKE BAY DRAINAGE AREA

Basin	*Implementable Storage (Acre-Feet)*	*Storage Based on 5% of Average Annual Flow (Acre-Feet)*
Susquehanna	1,200,100*	1,418,800
Potomac	395,800*	449,000
James	1,115,000	370,000*
Rappahannock	713,000	106,000*
York	0*	96,000

Storage Requirements

The salinity levels of the Chesapeake Bay are a function of many factors including the time history, magnitude, and location of freshwater inflows, ocean salinities, antecedent salinities, and tidal amplitudes. The possible combinations of these factors is nearly infinite. Because of this, it is not possible to select one set of minimum freshwater inflows which will assure that the plan formulation goals are met under all possible conditions. Rather, target salinities must be specified at critical locations and the required freshwater inflows computed based on the unique hydrographic and salinity conditions which exist, or are projected to exist, during the period of interest. Real time salinity monitoring, historic freshwater inflow records, and both estuarine and riverine models would be needed to accomplish this.

The Chesapeake Bay Study staff had intended to develop the sophisticated methodologies necessary to compute the amount of storage required to meet plan formulation goals under the unique hydrographic and salinity conditions addressed in this study. Three model tests were to be done in order to gather the data necessary to do this. *But, it was possible to conduct only one* of these tests meaning that much of the information needed was not available. It was decided, however, that it would be remiss to produce this report without at all addressing storage requirements. Therefore, the rather simplistic two-step methodology described in *Appendix B, Plan Formulation*, was developed to give at least some insight to the amount of reservoir storage needed to meet the various plan formulation goals. A short summary of this methodology is below. For clarity, it is described by illustrating its application in the situation where the goal is to maintain summer Base Drought salinity conditions during a Future Drought event. Storages for other conditions were computed in a similar manner.

1. Antecedent conditions must be satisfied if salinities are to be at Base Drought levels at the beginning of summer. It was determined from the hydraulic model test that, depending on the location in the estuary and the magnitude of inflow, it takes from 60 to 150 days for salinities to adjust to a change in freshwater inflow. Therefore, if Base Drought salinities are to be met at the beginning of summer, the Base Drought hydrograph must be in place 60 to 150 days prior to summer. The amount of storage needed to accomplish this was computed by determining the average difference (expressed in mgd) between Future Drought and Base Drought freshwater inflows during the antecedent period and multiplying this difference by the number of days in the period.

2. *The second step* involved determining the amount of storage required to maintain Base Drought salinities during the summer (the target season). This was done by multiplying by 90 days the difference (in mgd) between the Future Drought and Base Drought summer seasonal average freshwater inflow.

Phase I Plan Development

Phase I of the planning effort addressed only the Susquehanna River and "Main Bay". Its purpose was to identify the potentials for solving, through flow supplementation, the full range of identified problems. A series of plans were formulated for each problem species or species group. The first set of plans was designed to eliminate long term average damages. Sufficient freshwater inflow was provided to bring Future Average salinities back to Base Average salinities. The storage requirements were those needed to achieve salinity goals during one season of the year.

Early in the evaluation process, the feasibility of accomplishment of "long-term average" plans through the use of storage became doubtful. Practical considerations arose regarding the monitoring necessary to determine release schedules to accomplish long-term average goals. Thus, except for conservation plans, which would directly reduce future consumptive losses, long-term average plans were dropped. Conservation was looked at more closely in later iterations of plan formulation.

The second set of plans was designed to eliminate drought related damages. Sufficient freshwater inflow was provided to decrease salinities from Future Drought Levels to a series of predetermined goals. These goals ranged from Base Drought to Base Average levels of protection.

Inspection of Table IV-3 indicates that very large amounts of water would be needed to meet the Future and Base Average goals. It is clear that the storages required are far beyond that considered reasonable. In addition, sea-

sonal salinities greater than long-term average ones are not necessarily detrimental. These are part of the natural cycle and it is only during extreme drought events that high salinities have been specifically identified as a multi-resource problem. Of course, the effects of MSX and dermo on the oyster is of concern under all conditions. Any further penetration of them into the estuary should be prevented if at all possible. But, there is some question whether this should be done if the result is an upsetting of the balance of nature. Thus only a slight enhancement of Base Drought salinities is deemed feasible. In effect, the major objectives of the flow supplementation alternatives became restricted to furnishing sufficient water to make up for consumptive losses and to slightly enhance the Base Drought.

TABLE IV-3

STORAGES REQUIRED TO MITIGATE DROUGHT RELATED PROBLEMS IN MAIN BAY

Salinity Goal	*Storage (1000 Acre-Feet)*		*Supplemental Flow (mgd)*
	Low	*High*	
Future Drought (no action)	0	0	0
Base Drought	920	1,200	900
Future Average	9,500	12,300	10,100
Base Average	10,800	14,000	11,300

Phase II Plan Development

In Phase II of plan development, the focus was expanded to include all major tributaries to Chesapeake Bay. Early in this phase, however, permanent conservation in the upper western shore and in such important rivers as the Patuxent, York, Choptank, and Chester were eliminated from further consideration. It was obvious that increases in habitat resulting from either of these measures would be too small to produce meaningful benefits. Thus, storage and permanent conservation were addressed in detail only in the Susquehanna, Potomac, James, and Rappahannock Rivers in Phase II of plan development.

Emergency drought restrictions were also eliminated as independent alternatives because institution of these measures would produce only very small increases in habitat for short periods of time. Also, they would be difficult to implement and enforce in an area as large as the Chesapeake Bay Basin. Drought emergency measures do, however, have some potential in reducing the amount of reservoir storage that may be required.

As shown on Tables IV-4 thru IV-7, four alternative plans were developed for each of the four seasons of the year. There are therefore, a total of 16 plans for each major river. Each of these plans were oriented to achieving during the Future Drought the salinities associated with one of the following four flow conditions:

1. No Action—Future Drought Salinities

2. Conservation—The salinities resulting from a "medium" level of conservation (storage volumes are the amount required in lieu of conservation).

3. Base Drought—Base Drought Salinities

4. Base Drought Enhancement—A salinity condition one-half way between Base Drought and Future Average.

The location of the target salinities for the problem species under each of these conditions is shown by isohaline lines on Plates 1 thru 9. These plates are located at the back of this volume of the report.

The storage volumes required to attain each of these salinity goals under Future Drought conditions are shown on the tables. These are the volume of storage required to provide sufficient flow to allow achievement of target salinities during one season of the year. Also the storage volumes are sufficient to allow flow supplementation for two consecutive years to offset the effects of an assumed 3 year drought event.

Tables IV-4 thru IV-7 also show the habitat for the problem species and the change in habitat resulting from each plan. The organisms selected for display in this Phase II evaluation were restricted to those ranked as high priority by the Steering Committee. These were oysters, submerged aquatic vegetation, soft clams, *Macoma,* and those species dependent upon the oligohaline and tidal freshwater zones. No specific plans were formulated for sea nettles and wood borers (*Bankia* and *Teredo*). These species, however, were included in the evaluations of the effect of each flow supplementation plan.

Two criteria were established for evaluation and screening of the alternative plans:

1. Change in habitat—to be retained, a plan must provide at least 25 percent incremental increase in habitat for one of the six major species or associations. This applied to both storage and conservation plans.

2. Required Storage—the volume of storage required will not exceed that which has been defined as reasonable.

These criteria were applied to each plan to identify the most promising flow supplementation plans.

The reservoir storage and conservation plans that were retained after these criteria were applied are shown on Table IV-8. As can be seen, conservation in the Rappahannock River was deleted as this measure does not produce any significant benefits in this river.

Many of the reservoir storage plans were also eliminated. This includes all of the Winter plans, the Spring plan for the Susquehanna River, and all the Base Drought enhancement plans. This meant that Base Drought levels of protection are the most that can be achieved within the established criteria. Although storage plans providing less than this level of protection are feasible, they have not been specifically addressed in the remainder of this report.

TABLE IV-4

SUSQUEHANNA RIVER—MAIN BAY HABITATS
EFFECTS OF PLANS ON MAJOR RESOURCES DURING DROUGHT CONDITIONS

Plan		Storage Requirements	Oysters			Oligohaline Zone			Tidal Freshwater Zone			Submerged Aquatic Vegetation			Soft Clam			Macoma		
		(1,000 Ac-Ft)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)
SPRING																				
No Action	(1)	—				760	—	—	125	—	—	645	—	—						
Conservation	(2)	190-250				770	10	1	130	5	6	655	10	2						
Base Drought	(3)	850-1140				830	60	8	157	27	21	695	40	6						
Base Drought Enh	(4)	4530-5940				950	120	14	205	48	31	850	155	22						
SUMMER																				
No Action	(1)	—	450	—	—	120	—	—	29	—	—	390	—	—	1	—	—			
Conservation	(2)	210-270	525	75	17	135	15	12	40	11	38	395	5	1	15	14	1400			
Base Drought	(3)	920-1200	870	345	66	310	75	56	90	50	125	425	30	8	70	55	367			
Base Drought Enh	(4)	5230-6770	1120	250	29	410	200	95	120	30	33	540	115	27	120	50	71			
FALL																				
No Action	(1)	—				100	—	—	15	—	—							755	—	—
Conservation	(2)	210-270				115	15	15	15	0	0							815	60	8
Base Drought	(3)	920-1210				185	70	61	17	2	13							1105	290	36
Base Drought Enh	(4)	5130-6610				190	5	3	55	38	224							1260	155	14
WINTER																				
No Action	(1)	—				200	—	—	46	—	—									
Conservation	(2)	190-260				200	0	0	51	5	11									
Base Drought	(3)	260-1180				200	0	0	87	36	71									
Base Drought Enh	(4)	4450-6430				430	230	115	130	43	49									

TABLE IV-5

POTOMAC RIVER
EFFECTS OF PLANS ON MAJOR RESOURCES DURING DROUGHT CONDITIONS

Plan		Storage Requirements	Oysters			Oligohaline Zone			Tidal Freshwater Zone			Submerged Aquatic Vegetation			Soft Clam			Macoma		
		(1,000 Ac-Ft)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)
SPRING																				
No Action	(1)	—				145	—	—	110	—	—	230	—	—						
Conservation	(2)	36-48				140	-5	-3	115	5	5	240	10	4						
Base Drought	(3)	370-500				120	-20	-14	145	30	26	310	70	29						
Base Drought Enh	(4)	3050-3600				290	170	142	195	50	34	345	35	11						
SUMMER																				
No Action	(1)	—	295	—	—	150	—	—	15	—	—	150	—	—	1	—	—			
Conservation	(2)	48-60	310	15	5	155	5	3	20	5	33	160	10	7	2	1	100			
Base Drought	(3)	440-560	390	80	26	170	15	10	41	21	105	205	45	28	9	7	350			
Base Drought Enh	(4)	2520-3630	480	90	23	195	25	15	70	29	71	280	75	37	14	5	56			
FALL																				
No Action	(1)	—				47	—	—	2	—	—							120	—	—
Conservation	(2)	48-60				47	0	0	5	3	150							160	40	33
Base Drought	(3)	450-570				47	0	0	20	15	300							375	215	134
Base Drought Enh	(4)	1970-2880				110	63	134	35	15	75							430	55	15
WINTER																				
No Action	(1)	—				43	—	—	2	—	—									
Conservation	(2)	36-56				44	1	2	4	2	100									
Base Drought	(3)	380-540				55	11	25	17	13	325									
Base Drought Enh	(4)	2500-3260				130	75	136	85	68	400									

TABLE IV-6

JAMES RIVER
EFFECTS OF PLANS ON MAJOR RESOURCES DURING DROUGHT CONDITIONS

Plan		Storage Requirements	Oysters			Oligohaline Zone			Tidal Freshwater Zone			Submerged Aquatic Vegetation			Soft Clam			Macoma		
		(1,000 Ac-Ft)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)	Habitat (km²)	Change in Habitat (km²)	(%)
SPRING															NO SIGNIFICANT AMOUNT IN JAMES RIVER			NO SIGNIFICANT AMOUNT IN JAMES RIVER		
No Action	(1)	—				130	—	—	69	—	—	135	—	—						
Conservation	(2)	2-3				130	0	0	69	0	0	135	0	0						
Base Drought	(3)	180-220				107	-21	-18	93	24	35	126	-9	-7						
Base Drought Enh	(4)	2090-2530				110	3	3	126	33	35	146	20	16						
SUMMER																				
No Action	(1)	—	7	—	—	82	—	—	47	—	—	91	—	—						
Conservation	(2)	8	7	0	0	82	0	0	49	2	4	91	0	0						
Base Drought	(3)	200-240	15	8	114	82	0	0	81	32	65	91	0	0						
Base Drought Enh	(4)	1690-2110	42	27	180	86	5	6	91	10	12	105	14	15						
FALL																				
No Action	(1)	—				70	—	—	6	—	—									
Conservation	(2)	4-8				70	0	0	6	0	0									
Base Drought	(3)	200-240				61	-9	-13	20	14	233									
Base Drought Enh	(4)	1320-1610				67	6	10	50	30	150									
WINTER																				
No Action	(1)	—				76	—	—	12	—	—									
Conservation	(2)	2-3				76	0	0	12	0	0									
Base Drought	(3)	180-220				76	0	0	29	17	142									
Base Drought Enh	(4)	1780-2030				86	10	13	76	47	162									

TABLE IV-7

RAPPAHANNOCK RIVER
EFFECTS OF PLANS ON MAJOR RESOURCES DURING DROUGHT CONDITIONS

Plan		Storage Requirements	Oysters			Oligohaline Zone			Tidal Freshwater Zone			Submerged Aquatic Vegetation			Soft Clam			Macoma		
		(1,000 Ac-Ft)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)	Habitat (km²)	Change in Habitat (km²)	Change in Habitat (%)
SPRING																				
No Action	(1)	—				23	—	—	34	—	—	110	—	—		NO				
Conservation	(2)	5-7				24	1	4	34	0	0	110	0	0		SIGNIFICANT				
Base Drought	(3)	42-56				31	7	29	31	−3	−9	111	1	1		AMOUNT				
Base Drought Enh	(4)	540-660				55	24	77	40	9	29	145	34	31		IN				
SUMMER																RAPPAHANNOCK				
No Action	(1)	—	42	—	—	32	—	—	8	—	—	78	—	—		RIVER				
Conservation	(2)	5-7	45	3	7	33	1	3	8	0	0	80	2	3						
Base Drought	(3)	44-58	65	20	44	37	4	12	9	1	12	92	12	15						
Base Drought Enh	(4)	460-570	105	40	62	37	0	0	21	12	133	125	33	36						
FALL																				
No Action	(1)	—				17	—	—	3	—	—							24	—	—
Conservation	(2)	6-8				18	1	6	3	0	0							30	6	25
Base Drought	(3)	44-58				24	6	33	3	0	0							70	40	33
Base Drought Enh	(4)	420-510				29	5	21	12	9	300							85	15	21
WINTER																				
No Action	(1)	—				8	—	—	2	—	—									
Conservation	(2)	6-8				9	1	12	2	0	0									
Base Drought	(3)	42-56				18	9	100	3	1	50									
Base Drought Enh	(4)	510-610				30	75	67	23	20	666									

TABLE IV-8

RESULTS OF PHASE II SCREENING

Basin	Plan	Species Significantly Enhanced: Oysters	Oligohaline/Tidal Freshwater Zones	Low Salinity SAV	Soft Clam	Macoma
Susquehanna	Summer Base Drought	X	X	—	X	—
	Fall Base Drought	—	X	—	—	X
	Conservation	—	X	—	X	—
Potomac	Summer Base Drought	X	X	X	X	—
	Fall Base Drought	—	X	—	—	X
	Spring Base Drought	—	—	X	—	—
	Conservation	—	X	—	X	X
James	Summer Base Drought	X	X	—	—	—
	Fall Base Drought	—	X	—	—	—
	Spring Base Drought	—	X	X	—	—
Rappahannock	Summer Base Drought	X	—	—	—	—
	Fall Base Drought	—	X	—	—	X
	Spring Base Drought	—	X	—	—	—

TABLE IV- 9

MULTI-SEASONS PLANS
STORAGE REQUIRED TO ACHIEVE
BASE DROUGHT SALINITIES
(1000 Acre-Feet)

		No Conservation		With Conservation		With Conservation & Drought Emergency		Assumed Reasonable
River	Plan	low	high	low	high	low	high	Storage
Susquehanna	SU-3	920	1200	710	930	650	870	1,200
	SUFA-3	1360	1630	1050	1270	930	1150	1,200
Potomac	SU-3	440	560	390	500	360	470	1,200
	SPSU-3	620	760	560	680	530	650	400
	SUFA-3	640	760	570	680	520	630	400
James	SU-3	200	240	190	230	170	210	370
	SPSU-3	310	350	300	340	280	320	370
	SUFA-3	310	350	300	340	250	290	370
Rappahannock	SU-3	45	60	40	50	35	45	106
	SPSU-3	65	80	60	70	55	65	106
	SUFA-3	65	80	60	70	50	60	106

The Steering Committee, during its review of the problem identification process, established a set of priorities to be considered in plan formulation. It ranked the problem species or associations as follows:

Priority 1. Oysters, Oligohaline Zone, Tidal Freshwater Zone

Priority 2. Low Salinity, SAV, Soft Clam, *Macoma*

Priority 3. *Bankia, Teredo* and Sea Nettle

Of the remaining plans, only the summer Base Drought plans provide benefits to all three priority 1 species and associations. In addition, benefits are provided by these plans for two out of the three priority two species with only the *Macoma* being omitted. Clearly this summer Base Drought plan provides more benefits than any of the other plans and should be retained as a most promising alternative. Because available storage is sufficient to provide protection for only one season, individual plans for spring and fall were effectively eliminated from further consideration.

The next step in the process was to assess the potential for developing multi-season plans. The advantage of these type plans is clear if it is recognized that once the summer plan is implemented, only the amount of water needed to make up for the consumptive losses during the added season is required. The antecedent flow supplementation conditions are already met. This is illustrated on Table IV-9 where the storage required for both summer and multi-season plans are shown under three assumed levels of conservation.

A comparison was made between the storages required for each multi-season plan considered reasonable. It was found that both of the multi-season plans for the James and Rappahannock Basins met the criteria. They were, therefore retained as "Most Promising Alternatives."

In the Susquehanna Basin, it would be necessary to institute conservation measures to keep the storage within acceptable limits. Despite this, the summer-fall plan for the Susquehanna Basin has been retained as a most promising alternative.

Even with conservation and drought emergency measures, the storage required in the Potomac River far exceeds that considered reasonable. Multi-season reservoir storage plans for this basin were, therefore, dropped from further consideration. This left the following reservoir storage plans:

PLAN	BASIN
SUMMER PLAN	Susquehanna Potomac James Rappahannock
SUMMER—FALL PLAN	Susquehanna James Rappahannock
SPRING—SUMMER PLAN	James Rappahannock

CHAPTER V

Most Promising Alternatives

The plan formulation process has yielded the following most promising alternative solutions to the problems resulting from decreases in freshwater inflow to Chesapeake Bay.

ALTERNATIVE FLOW SUPPLEMENTATION	BASIN OR AREA
Conservation	Potomac Susquehanna
Reservoir Storage	
Summer Plan	Susquehanna Potomac Rappahannock James
Summer—Fall Plan	Susquehanna Rappahannock James
Spring—Summer Plan	Rappahannock James
Growth Restrictions	All Basins
CHESAPEAKE BAY MEASURES	
Oyster Bed Restoration	Bay wide
Catch Restrictions	Bay wide
Finfish Restocking	Bay wide

These alternatives have been developed in varying levels of detail. Conservation and reservoir storage were subjected to both a preliminary and a rigorous two phase screening process. Plans were formulated that specifically identified the amount of species habitat that could be protected. Those measures that did not produce significant increases in habitat were eliminated from further consideration.

On the other hand, no specific plans were developed for growth restrictions or the Chesapeake Bay measures. In the case of growth restrictions, information and precedences for defining and evaluating alternatives was not available. Similarly, the present state of the art knowledge of the features of the Chesapeake Bay measures is not sufficient to allow development of these plans beyond conceptual levels.

The "Most Promising Alternatives" are not totally independent ones. There are potential opportunities for combining them. For instance, the amount of reservoir storage required could be reduced or the supplemental freshwater inflows increased by the addition of conservation measures, emergency drought restrictions, and/or growth restrictions. This is very appealing. As designed, the reservoir storage alternatives do not provide protection beyond Base Drought levels. This means that damages to some of the problem species would remain. Of particular concern is the oyster. Significant damages to oysters from MSX and dermo have been documented during recent droughts that were much less severe than the Base Drought.

There are many other possible plan combinations far too numerous to

mention here. A few of them include simultaneous institution of Oyster Bar Restoration, Catch Restrictions and Finfish Restocking or adding these Chesapeake Bay alternatives to the flow supplementation plans.

Benefits of the Most Promising Alternatives

The benefits produced by each of the "Most Promising Alternatives" are summarized on Table V-1. The first part of the table indicates the level of protection offered by each alternative and the portion of the estuarine system that would receive direct benefits. The second part of the table displays the benefits produced by the plans in the terms of the resources addressed in problem identification.

The environmental benefits were identified in full consideration of the health of the Bay's biota, ecosystem functions and aesthetics. They have been divided into two categories. The first one includes only the species or species groups that were identified in this study as being significantly adversely impacted by reduced freshwater inflows. The second category addresses the remainder of the 57 study species. For clarity, the organisms included in the tidal freshwater and oligohaline zones are shown on Table V-2. Likewise the other species benefited have been listed on Table V-3 rather than Table V-1.

Commercial fishing, recreation and water users have been shown under the socio-economic benefits account. Included among the factors considered in developing these benefits were income and employment in the commercial fishing and recreation sectors, enhanced recreation opportunities, cost of water treatment, protection of health and safety and the preservation of traditions.

Flow Supplementation Measures

The flow supplementation alternatives are designed to prevent at least a portion of the damages that would be caused by increased consumptive losses of water and drought events. The plans that have been developed strive to provide those salinity levels in Chesapeake Bay that would optimize the health and size of the habitat for the identified problem species. This would produce not only environmental benefits, but,

TABLE V-1

Benefits of Most Promising Alternatives

	FLOW SUPPLEMENTATION MEASURES	
	RESERVOIR STORAGE *(Drought Only)*	
	SUMMER	SPRING-SUMMER
AREA BENEFITED	Main Bay, Potomac, Rappahannock, James	James, Rappahannock
LEVEL OF PROTECTION	Base Drought	Base Drought
ENVIRONMENTAL BENEFITS		
Problem Species or Groups*	Oysters, Oligo Zone, SAV, Soft Clam (MB, P)	Oyster (SU) O-Zone (SP & SU) SAV (SU)
Other Species	Will benefit all species adversely affected by increased salinities in summer (See Table V-3)	Will benefit all species adversely affected by increased salinities in spring & summer (See Table V-3)
SOCIO-ECONOMIC BENEFITS		
Commercial Fishery	Oysters, soft clams striped bass, shad	Oysters, striped bass, shad, soft clam
Recreation	*Less boat slips exposed to Bankia* (MB & P); Less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV) for waterfowl (MB, P, R)	Less nettles for swimming; improved sport fishing (striped bass shad); improved hunting due to more food (SAV) for waterfowl (R)
Water Users	Slight benefit in summer (MB, P, J)	Slight benefit in spring & summer (J)
OTHER BENEFITS	Will slightly reduce salinities at boundary with other tributaries during summer	Will slightly reduce salinities at boundary with other tributaries during spring & summer

LEGEND

Seasons when benefits occur	Seasons where benefits occur
SP — Spring	MB — Main Bay
SU — Summer	P — Potomac
FA — Fall	J — James
	R — Rappahannock

*Oligo Zone — Includes species in both Tidal Freshwater and Oligohaline Zones (See Table V-2)
Benefits occur in all areas if not noted.

CHESAPEAKE BAY MEASURES

	SUMMER-FALL	CONSERVATION (Drought & Average)	GROWTH RESTRICTIONS (Drought & Average)	OYSTER BED RESTORATION (Drought & Average)	FINFISH RESTOCKING (Drought & Average)	CATCH LIMITATIONS (Drought & Average
	Main Bay, James, Rappahannock	Main Bay, Potomac	Assumed Bay-wide	Bay-wide	Bay-wide	Bay-wide
	Base Drought	23% of BD (MB) 9-12% of BD (P)	Unknown	Unknown	Unknown	Unknown
	Oyster (SU) O-Zone (SU & FA) SAV (SU), Soft Clam (SU) *Macoma* (FA-MB, J)	Oyster (SU) O-Zone (All seasons) SAV (SP & SU) Soft Clam (SU) *Macoma* (FA)	Oysters (SU) O-Zone (All seasons) SAV (SP & SU) Soft Clam (SU) *Macoma* (FA)	Oysters	Striped, Bass, Shad	Oysters, Soft clam Striped Bass, Shad
	Will benefit all species adversely affected by increased salinities in summer & fall (See Table V-3)	Will benefit all species adversely affected by increased salinities (See Table V-3)	Will benefit all species adversely affected by increased salinities (See Table V-3)	None	None	None
	Oysters, striped bass, shad, soft clam	Oysters, striped bass, shad, soft clam	Oysters, striped bass, shad, soft clam	Oysters	Striped bass, shad	Oysters, striped bass, shad, soft clam
	Less boat slips exposed to *Bankia* (MB); less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & *Macoma*) for waterfowl (MB, R)	Less boat slips exposed to *Bankia*; less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & *Macoma*) for waterfowl	Less boat slips exposed to *Bankia*; less nettles for swimming; improved sport fishing (striped bass & shad); improved hunting due to more food (SAV & (*Macoma*) for waterfowl	None	Improved sport fishing (striped bass & shad)	Improved sport fishing (striped bass & shad)
	Slight benefit in summer & fall (MB, J)	Slight benefit all seasons	Slight benefit all seasons	None	None	None
	Will slightly reduce salinities at boundary with other tributaries during summer & fall	No discernable change	Unknown	None	None	None

the socio-economic benefits associated with the commercial fishing and recreation industries.

The fact that salinity levels are controlled has implication beyond the protection of the problem species. All other organisms adversely affected by decreasing freshwater inflow would also receive some degree of protection. This would result in additional environmental benefits. Also, there would be slight additions to economic benefits through the reduction in water treatment costs for those industries and municipalities that use the Chesapeake as a water supply source.

Reservoir Storage. Reservoir storage is a promising alternative in the Susquehanna, Potomac, Rappahannock and James River Basins. It could be used effectively only during a drought and would provide few, if any, long term average benefits. The measure, as formulated, provides sufficient storage to insure that salinities during the specified seasons are never greater than Base Drought levels for 2 consecutive years of a 3 year drought event. All "Main Bay" reservoir storage benefits were calculated as a function of the plans for the Susquehanna River.

As can be seen on Table V-1, three basic reservoir storage plans have been retained as "Most Promising Alternatives." These are a Summer plan, a Summer-Fall plan and a Spring-Summer plan. The Summer plan is viable in all four river basins. It provides benefits for all species rated priority 1 and 2 by the Steering Committee except *Macoma*. Also summer is the second most important season for the tidal freshwater and oligohaline zones.

The Summer-Fall plan would add benefits for the *Macoma* and the third most important season for the tidal freshwater and oligohaline zones. Although this type plan is not feasible in the Potomac River, benefits are provided for the majority of the estuarine systems.

The Spring-Summer plan provides the fewest benefits of the reservoir storage plans as it is a feasible alternative only in the Rappahannock and James Rivers. This means that salinities would be directly controlled in only a small portion of the estuarine system. The advantage of this plan would be maintenance of the size of the tidal freshwater and oligohaline zones in these two rivers during their two most important seasons.

It is clear that supplementing the freshwater inflows to Chesapeake Bay through reservoir storage would produce substantial benefits in the estuary. But, it should be emphasized that like the other most promising alternatives the reservoirs addressed in this study are not being recommended for construction; rather, they are measures that need to be further analyzed before any recommendations can be made. In particular, the upstream socio-economic and environmental impacts must be identified in detail to determine if the total benefits of reservoir storage outweigh the total costs. An important

TABLE V-2

STUDY SPECIES DEPENDENT ON TIDAL FRESHWATER AND OLIGOHALINE ZONES

SPECIES

Phytoplankton
- Tidal Freshwater Assoc.
- Oligo/low meso. Assoc.

Ceratophyllum demersum (SAV)
Tidal freshwater marsh assoc.

Brachionus calcyiflorus (rotifer)

Eurytemora affinis (copepod)

Scottolana canadensis (copepod)

Bosmina longirostris (cladoceran)

Limnodrilus hoffmeisteri (Oligochaete worm)

Scolecolepides viridis (polychaete worm)

Cyathura polita (isopod)

Gammarus daiberi (amphipod)

Alosa sapidissima (Am. shad)

Alosa pseudoharengus (alewife)

Morone saxatilis (striped bass)

Morone Americana (white perch)

Perca flavescens (yellow perch)

ingredient in these analyses are the local, regional and National perspectives.

Another point that should be emphasized is the meaning of the word "reasonable" as it relates to quantities of storage. This determination was based solely on technical considerations and experience in previous studies. For the most part, it is a function of the amount of water that can be stored without materially affecting the natural variability of flows in the main stem of the rivers. The work associated with this study appears to indicate that the storage of a quantity of water equivalent to the amount of consumptive losses that will accumulate in two seasons during a severe drought in the year 2020 is the outer limit of technically feasible "reasonable" storage. Certainly, more detailed studies are needed to ascertain if this level of storage can be economically, socially, and environmentally justified or if some lesser level of storage is more appropriate.

Conservation. Conservation is a viable measure in only the Susquehanna and Potomac River Basins. Although the increases in freshwater inflow provided by it would be small, the benefits could be rather significant. It would supplement freshwater inflows during all seasons of the year thereby providing both long term average and drought related benefits to all species and resources adversely affected by decreases in freshwater inflow.

Growth Restrictions. As previously noted, the growth restriction plan is not as well defined as the other flow supplementation alternatives. Even though the increases in freshwater inflows resulting from implementation of this alternative would in many cases be very small, it has been assumed that growth restrictions could be adopted Bay wide. It was not possible, however, to identify the level of protection that would be provided. Also, it was not possible to determine whether the plan would provide seasonal or year around benefits. For the purposes of the benefit display, however, it has been assumed that this measure would produce permanent increases in freshwater inflow. In this event, year-round benefits under both long term average and drought conditions would be provided for all organisms and resources adversely affected by decreased freshwater inflow to Chesapeake Bay.

TABLE V-3

EFFECTS OF REDUCED SALINITIES ON OTHER STUDY SPECIES

Species Benefited by Salinity Reduction

SPRING

Leptocheirus plumulosus — amphipod
Mesohaline phytoplankton
Acartia clausi — copepod

SUMMER

Prorocentrum minimum — dinoflagellate
Chrysaora qunquechirra (polyp) — sea nettle
Rangia cuneata — brackish clam

FALL

None

WINTER

Phthya valisineria — canvasback duck

Species Adversely Affected by Salinity Reduction

SPRING

Pectinaria gouldii — polychaete worm
Ampelisca abdita — amphipod crustacean
Polyhaline phytoplankton
Podon polyphemoides — cladoceran
Zostera marina — eelgrass

SUMMER

Mnemiopous leidyi — comb jelly, ctenophore
Streblospio benedicti — polychaete worm
Heteromastus filiformis — polychaete worm
Mercenaria mercenaria — hard clam
*Balanus improvisus** — barnacle
Chrysaora quinquecirrha — sea nettle
Leioslomus xanthurus (Adult) — spot
Brevoortia lyrannus (Adult) — menhaden
Urosalphinx cinarea — oyster drill
*Anchoa mitchilli** — bay anchovy
Polyhaline phytoplankton
Ruppia maritima — widegeon grass
Acartia tonsa — copepod
Evadne tergestina — cladoceran
Menidia menidia — Atlantic silversides
Micropogania undulatus (Adult) — Atlantic croaker
Zostera marina — eelgrass

FALL

Mulinia lateralis — coot clam

WINTER

Prorocentrum minimum — dinoflagellate
Brevortia tyrannus (Juv & Larvae) — menhaden
Micropoganias undulatus (Juv & Larvae) — Atlantic croaker
Leiostomus xanthurus (Juv & Larvae) — spot

*Due to predation.

Growth restrictions should be implemented only after they have been carefully thought out. It would be very difficult to control nationwide growth in population and, for the most part industry, through measures which are acceptable in our free society. Therefore, if growth restrictions are imposed in one particular drainage basin, there is a high probability that the growth in population or industrial activity would be transferred to another basin.

Chesapeake Bay Measures

Chesapeake Bay measures are management type alternatives that would repair rather than prevent long term average and drought related damages. These measures, however, have been retained as "Most Promising Alternatives" more for their future potential than their immediate application. "Oyster Bed Restoration" is the only one of them that has proven successful in maintaining or increasing species populations. In fact, even this alternative has been attempted only on a relatively small scale. There is no assurance that it is appropriate to use in alleviating damages as large as those caused by reduced freshwater inflow to Chesapeake Bay.

Even if the Chesapeake Bay Alternatives do prove to be feasible in the future, the benefits provided by them would be limited. Each of them is species specific. They would provide few, if any, benefits to organisms or resources other than those directly addressed by the alternative. In addition, because salinity would not be controlled, no benefits would be provided to the municipalities and industries using Chesapeake Bay as a water supply source.

Plans of Others

A primary consideration relative to a discussion of the "Most Promising Alternatives" is the existence of other plans. There are two plans for flow maintenance presently in effect in the Bay drainage basin. These are the Potomac Low Flow Allocation Agreement and the Susquehanna River Basin Commission's requirements for consumptive loss make-up during low flow periods. In the Metropolitan Washington Area, the Low Flow Allocation Agreement provides for an equitable means of allocating Potomac River water among the several major water supply agencies. The Agreement also stipulates that a certain amount of flow be allowed to enter the Potomac Estuary as environmental flowby. The signatories have adopted a 100 mgd value for minimum flowby to the estuary.

The minimum flow criteria, established by the Susquehanna River Basin Commission, specifies that "compensation shall be required for consumptive uses (of water) during periods of low flow." The regulation requires makeup of the amount consumed at streamflows equivalent to the 7-day, 10-year low flow. For the Susquehanna at Marietta, Pennsylvania, this minimum flow is about 2500 cfs. A review of the streamflow record for the 1960's drought, reduced by the projected 2020 consumptive losses, indicates this 2500 cfs low-flow criteria would be exceeded more than 250 days during a recurrence of the four-year event.

Risk and Uncertainty — Sensitivity Analysis

The probability for success of the most promising plans is a function of the many assumptions made in determining the environmental, economic and social effects of a potential reduction in freshwater inflow. To assess how changes in these principal assumptions could affect study findings, a discussion of uncertainties, risks, and sensitivities has been prepared. A summary of these is provided in the following paragraphs. A full discussion is provided in *Appendix B, Plan Formulation*.

TABLE V-4

COMPARISON OF PROJECTION SETS
SERIES E AND OBERS 1980
YEAR 2020

Parameter	*Series E (millions)*	*OBERS 1980 (millions)*	*Change Number (millions)*	*Change Percent (%)*
Population	26.8	20.4	−6.4	−24
Employment	12.2	10.1	−2.1	−18

NOTE: Statistical area includes the following Economic Areas: Baltimore, Washington, Philadelphia, Harrisburg, Richmond, and Norfolk.

OBERS 1980 Projections

A major assumption in this study was that projections done as part of the *Second National Water Assessment*, completed by the Water Resources Council in 1978, are the most appropriate definition of future water supply demand for the Chesapeake Bay Basin. The projection set used in the Assessment was the U.S. Department of Commerce's Series E. In 1981, a new projection set, termed OBERS 1980 was released. These new demographic and economic forecasts have implications relative to the water demand information used in this study.

A comparison of the original Series E projections (from the National Assessment), and the more recent OBERS 1980 projection sets, is shown in Table V-4. The population and employment data are aggregates of the six major economic areas influencing the Bay. Compared with Series E, the OBERS 1980 projection set shows approximately a 24 percent reduction in population, and an 18 percent reduction in employment.

An assessment of the effects of these changes on the water use projections themselves would be difficult without an analysis of each of the six major water use types. It is clear that estimates of consumptive loss and withdrawals of freshwater based on Series E projections are overstated assuming that OBERS 1980 projections more accurately depict the most probable future conditions. It is probably sufficient to note that the lower growth rates

estimated at present may simply forestall realization of certain critical levels of key variables, such as consumptive losses, until a later date. The true implications of such a delay for the study's conclusions or recommendations can only be guessed at because a delay in attaining a given level can be accompanied by significant changes in other relevant variables such as technology, consumer behavior, unanticipated shifts in agricultural irrigation policy or demands for water from out-of-basin.

Biological Uncertainties

In this study, the principal tool for identification of organism impacts has been quantification of potential habitat as defined by salinity, depth, substrate.

Determination of these direct effects was relatively straightforward. Uncertainties arise, however, in attempting to translate these variables into productivity and organism abundance. Many variables which originate both externally and internally to the estuarine system are not sufficiently understood to allow prediction, with a high degree of confidence, the end result of a perturbation such as a change in freshwater inflow.

To overcome these difficulties, and arrive at some assessment of the effects of estuarine health and productivity, a Biota Evaluation Panel was convened. The Panel's findings, in conjunction with the Corps' in-house social and economic analyses, were the basis of problem identification and plan development in this study. The confidence in the predictions varies with the species of concern. A discussion is provided for each major organism in the following paragraphs.

The confidence in the predictions made in this report is greatest for oysters. Flow supplementation plans were developed in light of the well documented (and apparently quite direct) relationship between oyster health and the range of disease organisms and predators. Salinity is a key determinant in limiting the destructiveness of these pest organisms.

Similar confidence is probably warranted for prediction for *Macoma* and soft clam. Similar to oysters, and other non-migratory benthics in general, the variation in one key habitat variable such as salinity can be used with a high degree of confidence as an indicator of organism survival.

TABLE V-5

DROUGHT RISK ANALYSIS

		Flow Durations			
River	*Season*	*1 Year*	*2 Year*	*3 Year*	*4 Year*
Susquehanna	Summer	1(41)	0	0	0
(82 years of record)	Fall	19 (3.7)	2(27.3)	0	0
	Winter	26 (3.0)	8 (9.1)	4(16.4)	1(41)
	Spring	17 (4.6)	2(27.3)	6/12.0)	2(27.3)
	Year	2(27.3)	0	0	0
Potomac	Summer	2(25.7)	0	0	0
(77 years of record)	Fall	1(38.5)	1(38.5)	0	0
	Winter	6(11.0)	11 (6.4)	5(12.8)	1(38.5)
	Spring	16(4.5)	14 (5.1)	9 (7.7)	5(12.8)
	Year	2(25.7)	1(38.5)	1(38.5)	0
James	Summer	5(12.3)	0	0	0
(74 years of record)	Fall	5(12.3)	1(37)	0	0
	Winter	8 (8.2)	9 (7.4)	6(10.6)	4(14.8)
	Spring	7 (9.3)	7 (9.3)	3(18.5)	2(24.7)
	Year	1(37)	1(37)	0	0
York	Summer	7 (8.9)	1(15.5)	1(15.5)	1(15.5)
(31 years of record)	Fall	1(15.5)	2(10.3)	0	0
	Winter	1(15.5)	1(15.5)	1(15.5)	1(15.5)
	Spring	1(15.5)	2(10.3)	1(15.5)	1(15.5)
	Year	1(15.5)	2(10.3)	1(15.5)	0
Rappahannock	Summer	4(13.0)	0	1(32.5)	0
(65 years of record)	Fall	4(13.0)	2(21.7)	0	0
	Winter	6 (9.3)	7 (8.1)	3(16.3)	3(16.3)
	Spring	13 (4.6)	7 (8.1)	4(13.0)	3(16.3)
	Year	2(21.7)	2(21.7)	2(21.7)	0

( ) Recurrence interval in years.

The relationships involved in the health and productivity of submerged aquatic vegetation are not as distinct. Due to unknowns in the relationship between changing salinity regimes and the distribution and abundance of SAV, the confidence in the predictions for SAV presented in this report are somewhat less than for oysters, soft clam and *Macoma*.

Uncertainties regarding the conclusion for finfish are probably greater than for any of the other major organisms or groups of organisms. The direct cause and effect relationship between re-

duced freshwater inflow and fish stocks is not well established. An obstacle in estimating impacts on fisheries stocks is that any change in populations due to decreased freshwater inflow may not be discernible from "normal" population variation. Thus, estimates of varying commercial fisheries catch should be considered the most uncertain of all estimates presented in this report.

Frequency

The frequency of recurrence of drought events is important in evaluating the risks associated with the "No Action" plan. To investigate this, the seasonal average flows for the period of record were computed and compared to those of the 60's drought. All discrete flow periods which were equal to or less than the seasonal averages for the 60's drought were accumulated. The results of this, along with computed recurrence intervals, are presented in Table V-5. Overall, it appears that the 1960's drought was the worst case drought scenario, especially in the critical summer and fall periods.

CHAPTER VI

Findings and Recommendations

Findings

Chesapeake Bay is a vast, complex estuarine system. Like all estuaries, it is dependent upon the quantity and pattern of inflow of freshwater from its tributaries to maintain the salinity regime that characterizes the ecosystem. But, population and economic activity in the Chesapeake Bay Basin is predicted to grow substantially by the year 2020. This may result in a need to use the Bay's tributaries as a source to satisfy an ever increasing water supply demand. Much of this water will be used consumptively thereby causing a marked reduction in the quantities of freshwater flowing into the Bay.

The increase in estuarine salinities caused by these consumptive losses as well as those associated with drought events have been estimated through tests on the Chesapeake Bay Model. Through an innovated methodology, it was found that the large increases in salinities during a drought or less dramatic increases over a long period of time produce significant adverse impacts on many of the aquatic species. It was also found that increased salinities could contaminate the water supplies for the municipalities and industries located along the shores of Chesapeake Bay. These findings led to the formulation of a series of plans called the "Most Promising Alternatives." A summary of the findings of the Chesapeake Bay Low Freshwater Inflow Study is as follows:

1. Water supply demands in the Chesapeake Bay Basin have been estimated to increase from 4370 mgd in the year 1965 to 5990 mgd in 2020. The increase in consumptive losses associated with this is 2060 mgd.

2. The projected increases in consumptive losses of water between the year 1965 and 2020 are projected about 2 to 11 percent of the long term average monthly freshwater inflow to Chesapeake Bay and nearly 57 percent of the lowest monthly average inflow.

3. The Susquehana River is the Bay's largest tributary. It contributes over 85 percent of the freshwater inflow above the Patapsco River and over 50 percent of the total freshwater inflow. The increases in consumptive losses are expected to be about 1 to 10 percent of the long term average monthly flow of this river and about 50 percent of the lowest monthly average inflow.

4. The relationship between freshwater inflow to Chesapeake Bay and salinity levels is very complex. At the present time, the changes in salinity levels caused by variable freshwater inflows can be approximated only through models, (such as the Chesapeake Bay Model), that can simulate the three dimensional aspects of the estuarine system.

5. The Low Freshwater Inflow Problem Identification Test provided data that reasonably represent the direction and magnitude of the up-Bay displacement of isohalines resulting from drought events or the decreases in freshwater inflow caused by consumptive losses. It was appropriate to use these test results as the basis for ecological evaluations and predictions.

6. The following conclusions can be made from the data provided by the Low Freshwater Inflow Problem Identification Test.

a. There would be no perceptible changes in water surface elevations or velocities caused by reductions in freshwater inflow of the magnitude addressed in this study.

b. Salinities in the Chesapeake Bay and its tributaries increased as a function of both the drought event and consumptive losses of water. On a seasonal average basis, the maximum difference between Base Average and Base Drought conditions was about 5 ppt. Similarly, the maximum difference between base and future conditions (effects of consumptive losses) was about 2 to 4 ppt.

c. The movement upstream on the isohalines was the most important aspect of the seasonal average salinity change in those portions of the work involving biological analyses. In both the lower and upper portions of the Bay, the isohalines were about 5 to 20 miles further upstream under Base Drought conditions than they were under Base Average conditions. The movement in the mid Bay was quite significant approaching 70 miles. Similarly, the isohalines were about 5 to 15 miles further upstream at the mouth and head of the Bay under Future Average or Drought conditions than they were under Base Average or Drought conditions. In the mid Bay the movement approached 40 miles.

d. It takes the Bay approximately 6 to 9 months of average inflows to recover to a state of dynamic normalcy following a drought.

7. The model test produced salinity distribution patterns that were never before emphasized. One of these was a phenomenon whereby the isohalines took the shape of a "tongue." There were regular extensions of freshwater over the deeper portions of the Bay which results in a tongue like displacement of that portion of the isohaline over the channels. This phenomenon is contrary to the commonly assumed constant increase in salinities across the Bay. But, the existence of it in the prototype was verified through careful inspection of field data and consultations with expert oceanographers.

8. Another hydraulic phenomenon brought to the forefront by the model test was the influence of tides on vertical mixing. Apparently, the neap tide does not contain sufficient energy to significantly affect mixing. On the other hand, there is a demonstrated tendency for the spring tide to "break up" the vertical salinity stratification.

9. At the present time, there is some question relative to the effects of the Chesapeake and Delaware Canal on the salinities of Chesapeake Bay. Although several studies of the canal have been completed, its dynamics are so complex that it is difficult to make a conclusion on the magnitude and direction of the net flow of water through it.

10. There are few, if any, existing methodologies that could be used in determining the impacts of changes in salinity on species populations. A new methodology was therefore developed. This involved the selection of a group of species which is representative of the biota of the Chesapeake, the mapping of the potential habitat for each of these species under various freshwater inflow conditions, and the formation of a panel of scientific experts to interpret the significance of habitat change. It was found that:

a. The use of a group of species to represent all the plants and animals of Chesapeake Bay is an appropriate technique.

b. Change in habitat is an appropriate technique for characterizing the biological change in the estuary resulting from decreasing freshwater inflows.

c. The state of the art knowledge of the interactions among species and the other physical and biological factors that affect their life cycles is not sufficiently advanced to use ecosystem models in interpreting how changes in habitat affect estuarine species. Of particular concern are the interactions among organisms and the role of freshwater inflow in circulation, the nutrient budget, sediment input and distribution, water temperature and the movement of non-motile organisms.

d. There is sufficient knowledge among the expert scientists of the Bay community to make qualitative judgements relative to the impacts on the study species of habitat change.

11. The seasonal variations in freshwater flow (i.e., high spring and low fall inflows) are very important to the health of the Bay's biota.

12. Upstream shifts in habitat will frequently move species into lower valued areas.

13. The changes in habitat caused by reductions in freshwater inflow can have both beneficial and detrimental effects. The detrimental impacts far outweigh the beneficial ones.

a. The most serious impacts would be to the oyster. Although the oyster normally thrives in salty water, so do its parasites and diseases. Estimates of the net loss in oysters due to the rapid spread of these organisms range from 50 percent under Future Average inflow conditions to over 85 percent under Future Drought conditions.

b. The size of the oligohaline and tidal freshwater zones will be significantly reduced. Over 20 species are dependent for their health on the maintenance of the size of these zones.

c. The populations of soft clams will be significantly reduced.

d. Populations of low salinity submerged aquatic vegetation and *Macoma balthica* would also be significantly reduced. Both of these species serve as primary food for many varieties of waterfowl.

14. The impacts of decreasing freshwater inflow on the two municipalities and many industries that use the estuary as a water supply source are small. Both municipalities and most industries are already taking the actions necessary to cope with the effects of increased salinity intrusion.

15. The increase in the number of beaches affected by sea nettles will be relatively small.

16. There will be a significant reduction in the population of the fish and waterfowl now preferred by the sports fisherman and hunter. There is, however, evidence that the sportsmen will switch to other species as the populations of their favored ones dwindle.

17. There will be a significant increase in the number of boat slips that would be exposed to wood borers such as *Bankia* and *Teredo*.

18. The commercial fishing industry would be seriously affected by decreases in freshwater inflow. Average annual damages are estimated to vary from $25 million to $30 million. During a drought event, damages could vary from $70 million to $80 million. By far, the majority of the damages would be to the oyster industry.

19. The projected losses in the commercial fishing and recreation industries could have far reaching consequences to many of the Bay traditions and the values of the recreation experience.

20. No specific plan has been developed to solve the problems caused by consumptive losses of water and drought events. Rather, the work has been carried only far enough to identify "Most Promising Alternatives." These are:

FLOW SUPPLEMENTATION
- Reservoir Storage
- Conservation
- Growth Restrictions

CHESAPEAKE BAY
- Oyster Bed Restoration
- Catch Limitations
- Finfish Restocking

It should be emphasized that no recommendations are being made for the immediate implementation of any of these alternatives. Rather further analyses are needed that will lead to the development of specific plans for coping with the consequences of decreases in freshwater inflows to Chesapeake Bay. In the meantime, it would be prudent to consider these consequences in all future actions related to the use, preservation, and enhancement of the Bay.

21. It is realized that demographic and economic projections more recent than those used in this study indicate that the magnitude of consumptive losses used as the basis for the foregoing analyses may not be realized in the year 2020. It is believed, however, that under any circumstances, the magnitude of increases in consumptive losses will be sufficient to be of real concern and that the Low Freshwater Inflow study provides a framework for the development of corrective actions.

22. Flow supplementation measures are the only methods available for controlling habitat size and contributing to the health of all problem species. On the other hand, Chesapeake Bay Measures are remedial ones that are oriented to restoring damaged resources. Also, these measures provide benefits to only those species for which they were designed.

23. Conservation measures would produce only small increases in freshwater inflows. It is, however, a proven, effective means of reducing water demands and to some extent, consumptive losses. It would provide year-round benefits. Innovative measures oriented to reducing consumptive losses should be developed.

24. The salinity levels of Chesapeake Bay are a function of many factors including freshwater inflow, antecedent salinities, and tidal amplitude. Because of this, it is not possible to select one minimum freshwater inflow which will insure that target salinity levels are never exceeded. In order to implement the reservoir storage alternative, a sophisticated system must be developed to allow the prediction of near term future estuarine salinities, the formulation of the quantities of freshwater inflow that must be maintained during critical periods, and the determination of the quantities of water which must be released from storage. At the present time, no such system is available.

25. Programs for the preservation and enhancement of Chesapeake Bay are presently being formulated and implemented. The success of these programs may be partially contingent on full consideration of the consequences of reduced freshwater inflow to Chesapeake Bay.

26. Both the physical and biological processes of Chesapeake Bay are very complex. In many cases, the scientist has just begun to understand them. It is recognized that it would not be prudent to wait until there is a full understanding of the Chesapeake to implement programs to solve its problems. However, advances in the state of the art knowledge is necessary to not only assess the effectiveness of ongoing programs, but, to formulate new ones.

Recommendations

Based on the above findings, it is recommended that:

1. The "Most Promising Alternatives" be further refined and a definitive plan be developed for coping with the effects of drought events and consumptive losses of water. Included in the work should be analyses and research that would lead to a better understanding of the alternatives and the actions which must be taken to insure their success. Also, both upstream and estuarine benefits and costs should be identified in detail.

2. All future efforts related to solving the problems of the Chesapeake Bay and all plans for use of its waters fully consider the effects of the proposed actions on freshwater inflows to the Bay. Where possible, all plans should incorporate features that minimize the adverse impacts associated with increasing consumptive losses of water and drought events. They should also strive to maintain the natural seasonal variations in freshwater inflow.

3. The conservation of water be fully considered in the development of future plans and that emphasis be placed on uncovering new methods oriented to substantially decreasing consumptive losses of water.

4. Research be undertaken that would lead to the ability to develop ecosystem models. Included in this would be studies that would allow a better understanding of the physical and biological functions of the Bay. Emphasis should be placed on those processes that are controlled by or related to freshwater inflow to Chesapeake Bay.

5. Studies be undertaken to determine the magnitude and direction of water flow through the Chesapeake and Delaware Canal and its effects on the salinities of Chesapeake Bay.

GLOSSARY

acre-foot:	a measure of water volume, equivalent to an acre of water surface one foot deep.
aesthetics:	people's perceptions of beauty or artistic values in the environment.
algae:	group of plants, variously single celled, colonial, or filamentous.
anadromous:	a type of fish that ascends rivers from the sea to spawn — examples in Chesapeake Bay include shad and alewife; striped bass are considered semi-anadromous.
aquatic:	of or pertaining to fresh or salt water; growing or living in or upon water.
Base Average:	long-term average freshwater inflow conditions; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.
Base Drought:	historical freshwater drought inflow conditions from 1963 to 1966; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.
Bay Region:	the geographical area which includes those counties or SMSA's which are located on Chesapeake Bay, approximately to the head-of-tide; same as "Study Area."
benthic:	of or pertaining to the bottom of a water body.
benthos:	those organisms living on or in the bottom of a water body.
biomass:	the living weight of a plant or animal population, usually expressed on a unit area basis.
biota:	the plant and animal life of a region.
bloom:	an unusually large number of organisms of water, usually algae, made up of one or a few species.
brackish water:	a mixture of salt water from the ocean and freshwater from land drainage; usually considered to have a salinity greater than 1 part per thousand.
cfs:	cubic feet per second.
community:	(in biology) an accumulation of diverse organisms living together in an orderly, interrelated manner.

consumptive loss: the portion of the water used for public, agricultural, industrial and electric power cooling usage that is lost from streamflow because of evaporation, incorporation into products, etc. (equivalent to "withdrawal" minus "discharge")

copepods: any of a subclass of small crustaceans of fresh or saline waters; a component of the zooplankton.

crustacean: any of a class of arthropods, including shrimp, crabs, and barnacles.

detritus: a non-dissolved product of disintegration or decay; organic detritus forms the basis of the estuarine food chain.

dissolved oxygen (DO): oxygen gas dissolved in water — necessary for life of fish and other aquatic organisms.

dissolved solids: a measure of the amount of organic and inorganic material which has been chemically dissolved in water.

dockside value: in commercial fishing, the value of a harvest to the fishermen before it is resold to distributors and wholesalers.

drainage basin: the area of the land from which all precipitation, less evapotranspiration and other losses, eventually discharges to a river or Bay.

drought: a prolonged period of dry weather or lack of rain; in this study it generally refers to a period similar to the drought of the mid-1960's that resulted in some of the lowest recorded streamflows in the Bay area.

ecosystem: the interacting system of living things and their physical and chemical environment.

endangered species: a plant or animal in danger of extinction throughout all or a significant portion of its range; currently listed under the provisions of the Endangered Species Act of 1973.

epifauna: aquatic species which live attached, on or above the bottom.

epiphytic: living on the surface of plants.

estuary: a partially enclosed body of water, with a connection to the ocean, in which freshwater from overland drainage is mixed with saline water moving in from the ocean; also that portion of a stream or river influenced by the tide of the body of water into which it flows.

euhaline: of or pertaining to waters of greater than 30 ppt salinity.

euryhaline: able to exist in a wide range of salinities; as opposed to "stenohaline."

eutrophic: abundant in nutrients and having high rates of productivity, frequently resulting in oxygen depletion below the surface layer.

evapotranspiration: the combined loss of water from a given area during a specified period of time by evaporation from the soil or other surface and by transpiration from plants.

Fall Line: the geological boundary line where sedimentary formations of the Coastal Plain thin out as they come into contact with the harder crystalline rocks of the Piedmont Plateau; generally coincides with the head-of-tide on western shore tributaries.

finfish: that portion of the aquatic community made up of the true fishes as opposed to invertebrate shellfish.

flow meter: an instrument for measuring current speed and direction.

food chain: the transfer of food energy from plants or organic detritus through a series of organisms, usually four or five, consuming and being consumed.

freshwater: of or living in water that is not salty; usually contains less than 0.5 ppt salinity.

Future Average: Base Average freshwater inflows reduced by projected consumptive losses in 2020; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.

Future Drought: Base Drought freshwater inflows reduced by projected consumptive losses in 2020; also, salinity conditions resulting therefrom, as determined by hydraulic model testing.

habitat: the total environmental condition affecting an organism, population or community; in this study typically including salinity, depth, substrate and existence of other organisms (predators, competitors and food organisms).

heavy metals: metals such as mercury, lead, zinc, chromium, cadmium, and arsenic, which are of importance because of their toxicity in relatively low concentrations to plants and animals and their relatively long lives.

hydrodynamic: of, derived from, operated by or having to do with the action of water.

infauna: aquatic species which burrow into the substrate.

invertebrate: any animal lacking a backbone (e.g., insects, mollusks and crustaceans).

isohaline: a line connecting all points of equal salinity.

juvenile:	a fully developed but immature life stage.
larva:	an early developmental stage of an animal which changes structurally to become an adult (e.g., caterpillars, tadpoles).
life cycle:	the series of life stages in the form and mode of life of an organism, i.e., between successive recurrences of a certain primary stage such as the spore, fertilized eggs, seed, or resting cell.
marsh:	low, wet, soft land; in the Bay, often synonymous with wetlands.
mesohaline:	of or pertaining to salinities which range between 5 and 18 ppt.
mgd:	millions of gallons per day.
motile:	capable of spontaneous movement.
neap tide:	tide of decreased range which occurs about every two weeks.
neckton:	the actively swimming aquatic animals (e.g., fish).
non-tidal current:	any current that is caused by other than tide producing forces; includes currents generated by wind and water density differences.
nutrients:	organic and inorganic chemicals necessary for the growth and reproduction of organisms.
oligohaline:	of or pertaining to low salinity concentrations; in this study, relates to the salinity range of 0.5 to 5.0 ppt.
organism:	any individual plant or animal.
photosynthesis:	the process in plants of production of carbohydrates from carbon dioxide and water, using sunlight as energy, and chlorophyll as a mediator.
phytoplankton:	small, freely floating forms of aquatic life (e.g., algae, diatoms, etc.).
piscivorous:	feeding on fishes.
plankton:	the passively drifting or weakly swimming organisms in marine or fresh waters.
polyhaline:	of or pertaining to salinities which range between 18 and 30 ppt.
ppt:	parts per thousand.
predator:	an organism living by capturing and feeding upon other animals.
primary consumer:	an organism which consumes green plants.
productivity:	the rate of production of organic matter produced by biological activity in an area (measured in units of weight or energy per unit volume or area and time).

riparian doctrine: unwritten law historically recognized in the Eastern States, guaranteeing stream flows be undiminished in quantity or quality due to unreasonable upstream uses.

risk: the chance of injury, damage or loss; often quantifiable as a probability of occurrence, such as the risk of a drought.

salinity: a measure of the dissolved solids content of water. The amount of chlorinity or electrical conductivity in a sea water sample is used to establish salinity; seawater is about 35 parts per thousand salinity (by weight); drinking water standards allows a maximum of 0.25 ppt salinity.

secondary consumer: an organism which consumes the primary consumer.

shellfish: aquatic animals having a shell or exoskeleton, usually mollusks (clams and oysters).

spawn: to produce or deposit eggs, sperm, or young.

species: a distinct kind; a population of plant or animal all having a high degree of similarity and that can generally only breed among themselves.

spring tide: tide of increased range which occurs about every two weeks when the moon is new or full.

stenohaline: of organisms which can endure only a narrow range of salinities.

substrate: bottom sediments — mud, sand, clay, silt, etc.

suspended solids: undissolved material in water, includes both organic and inorganic substances.

synergistic: interactions of two or more substances or organisms producing a result that any was incapable of independently.

trophic level: all organisms in a complex community that derive their food a common step away from the primary producers (green plants).

uncertainty: lack of certainty; doubt; relates in this study to estimates of such variables as future population growth, fishery productivity, etc.

vertebrate: those animals possessing a backbone or spinal column, i.e., fishes, birds, reptiles, amphibians, and mammals.

waterfowl: birds frequenting water, including game birds such as ducks and geese.

wetlands: areas characterized by high soil moisture and high biological productivity, where the water table is at or near the surface for most of the year.

withdrawal: water taken from a surface or groundwater source for an offstream use (equivalent to "intake").

zooplankton: the animal forms of plankton, including certain types of protozoans, crustaceans, jellyfishes, etc., and the eggs and larvae of many benthic and necktonic animals.

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Citizens Program for the Chesapeake Bay, Inc.

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Susquehanna River Basin Commission

Robert J. Bielo

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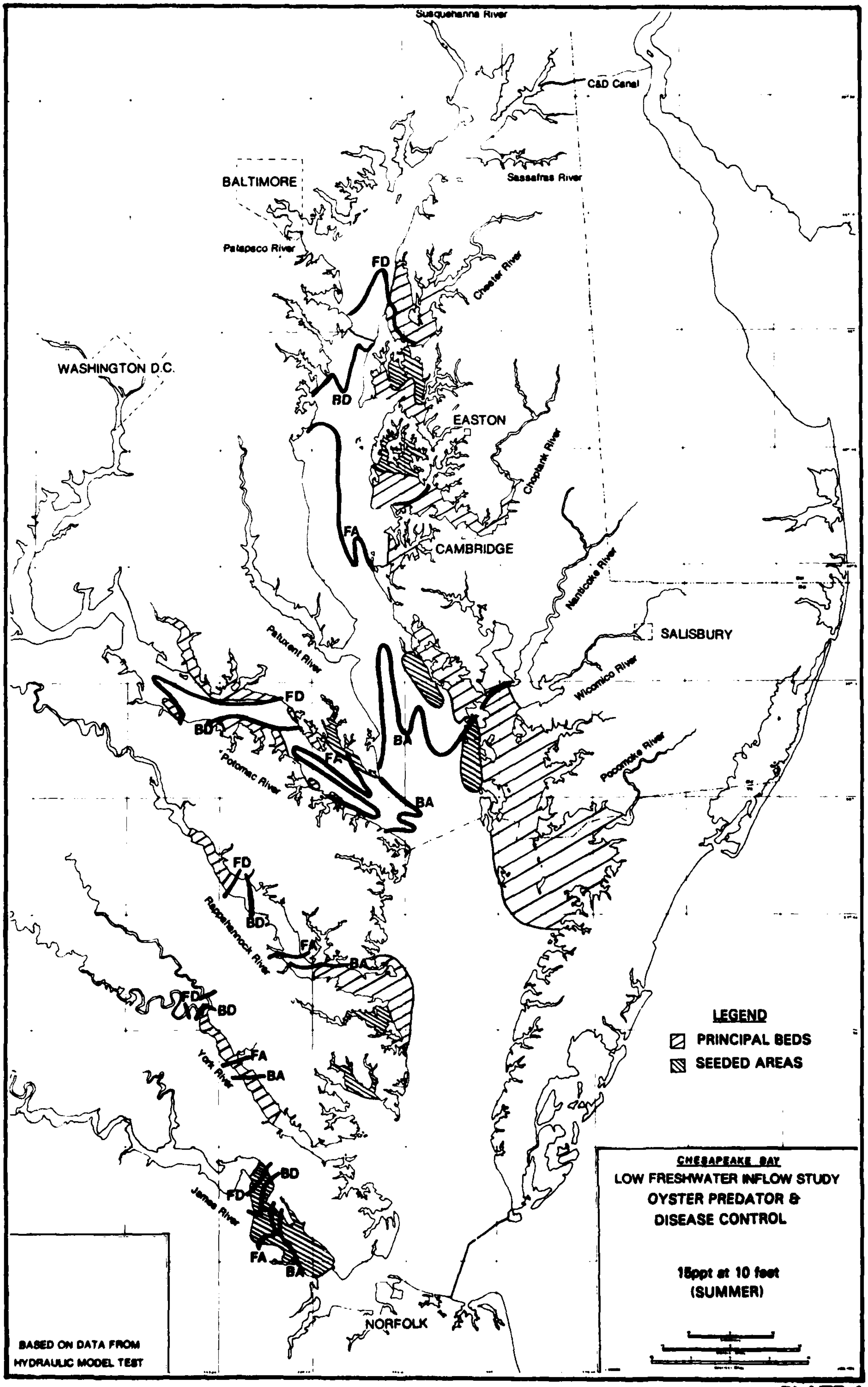
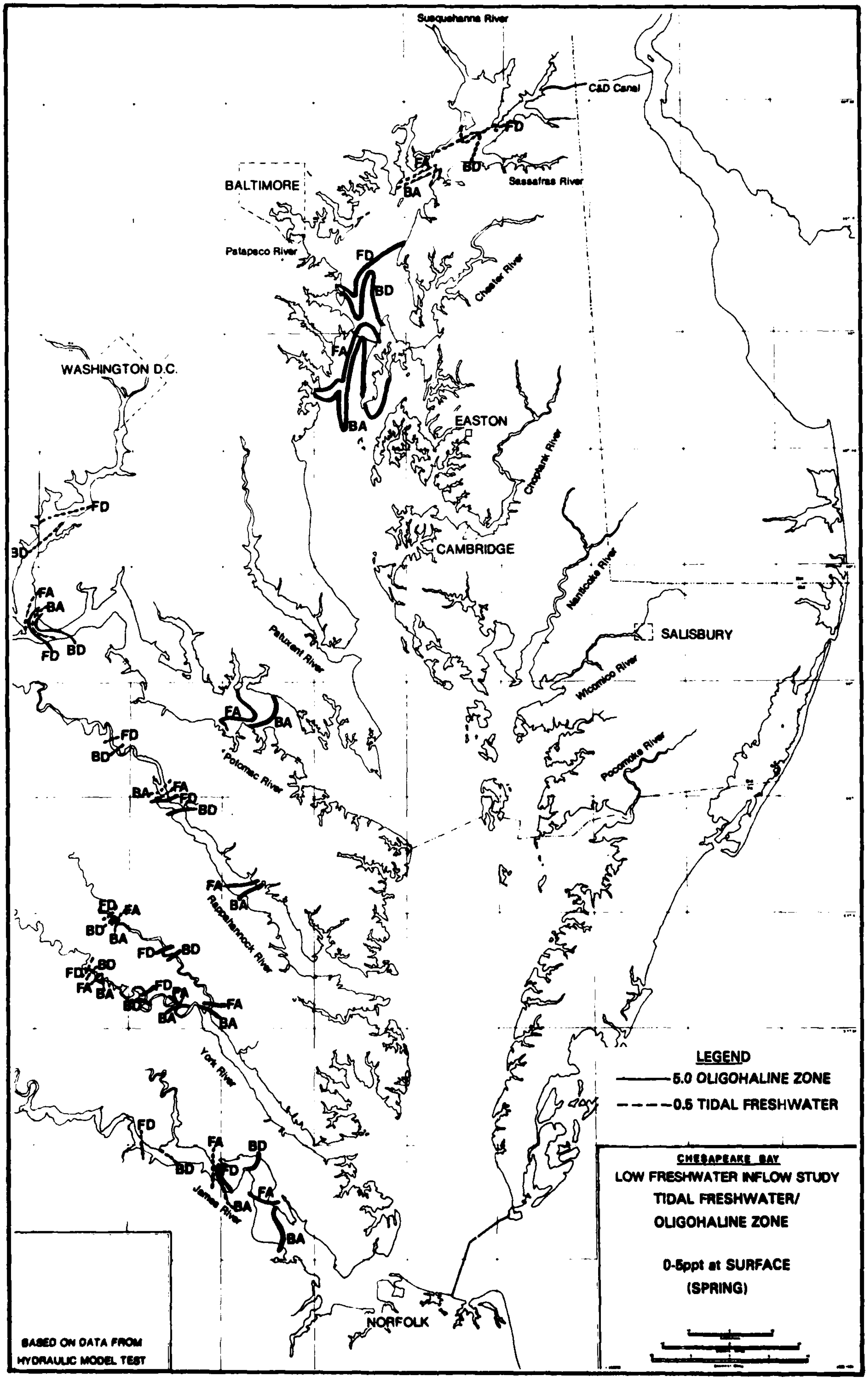
Credit is also due to many others who contributed to the Chesapeake Bay Study and to this report.



Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
Patapsco River
FD
Chester River
WASHINGTON D.C.
BD
EASTON
Choptank River
FA
CAMBRIDGE
Nanticoke River
SALISBURY
Patuxent River
Wicomico River
FD
BD
BA
FF
Potomac River
Pocomoke River
BA
FD
BD
Rappahannock River
FA
BA
FD
BD
York River
FA
BA
LEGEND
PRINCIPAL BEDS
SEEDED AREAS
BD
FD
James River
FA
BA
NORFOLK
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
OYSTER PREDATOR &
DISEASE CONTROL
15ppt at 10 feet
(SUMMER)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 1



Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
Patapsco River
Chester River
WASHINGTON D.C.
EASTON
Choptank River
CAMBRIDGE
Nanticoke River
SALISBURY
Patuxent River
Wicomico River
Potomac River
Pocomoke River
Rappahannock River
York River
James River
NORFOLK
FD
BD
FA
BA
LEGEND
5.0 OLIGOHALINE ZONE
0.5 TIDAL FRESHWATER
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
TIDAL FRESHWATER/
OLIGOHALINE ZONE
0-5ppt at SURFACE
(SPRING)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 2

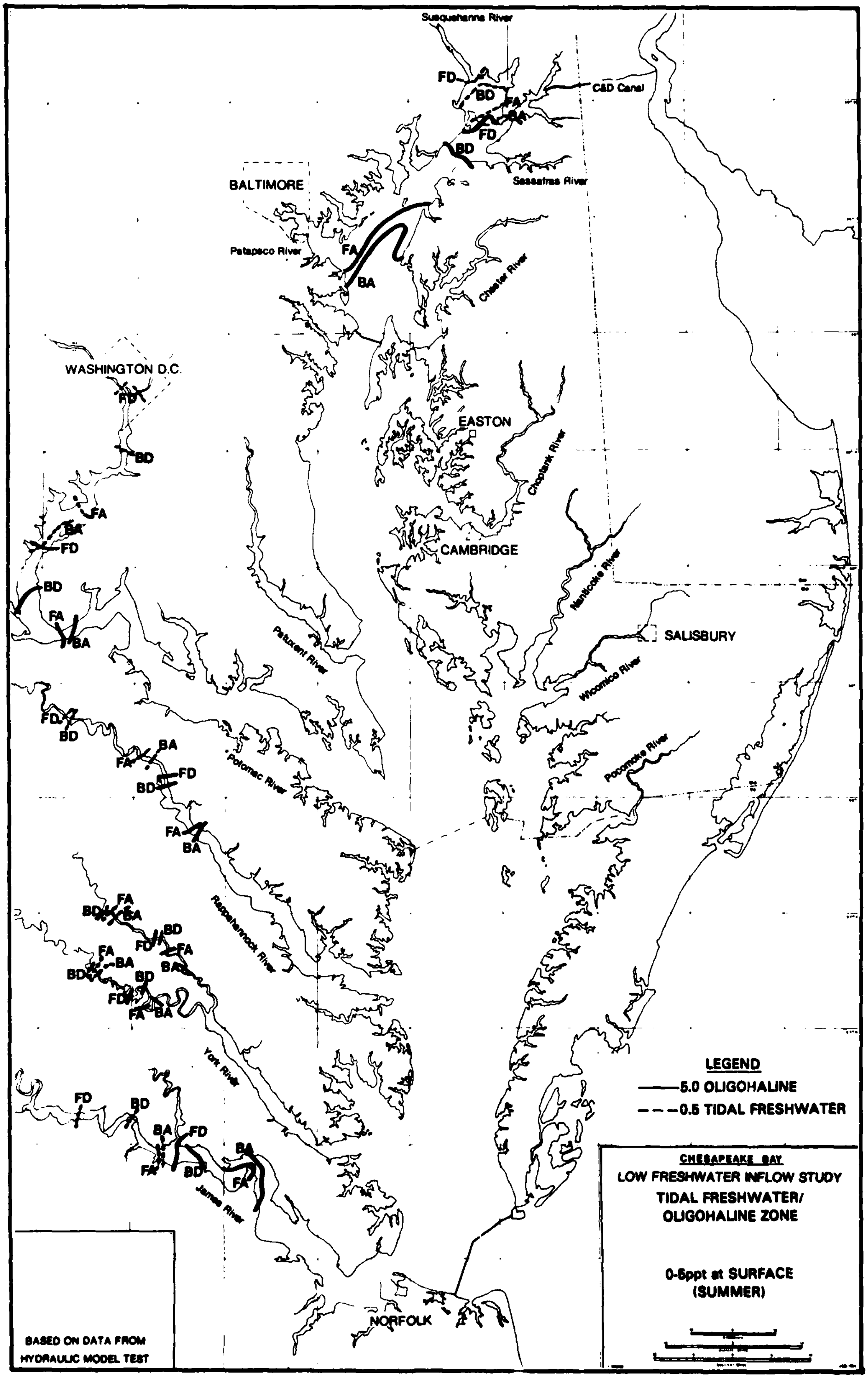
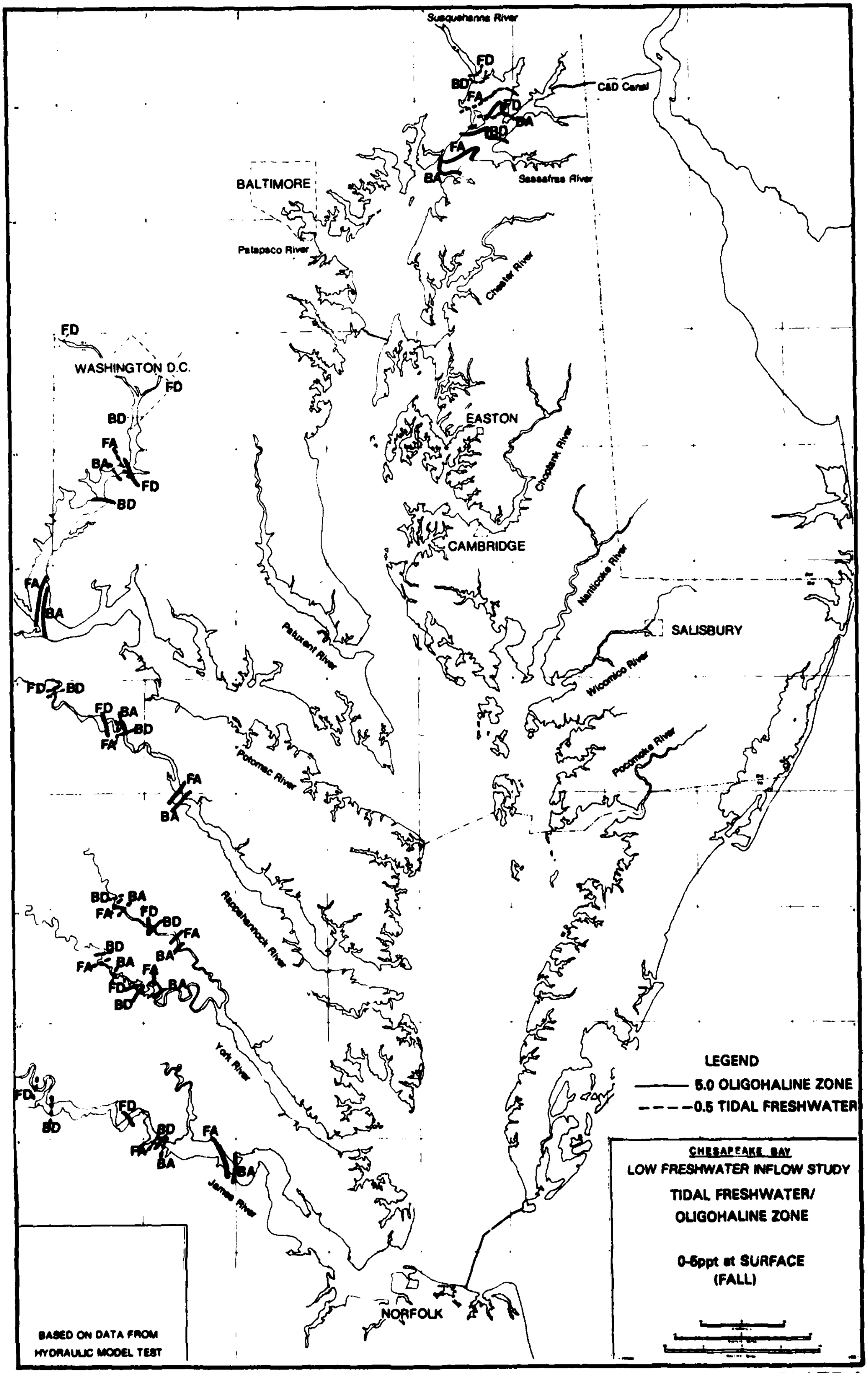
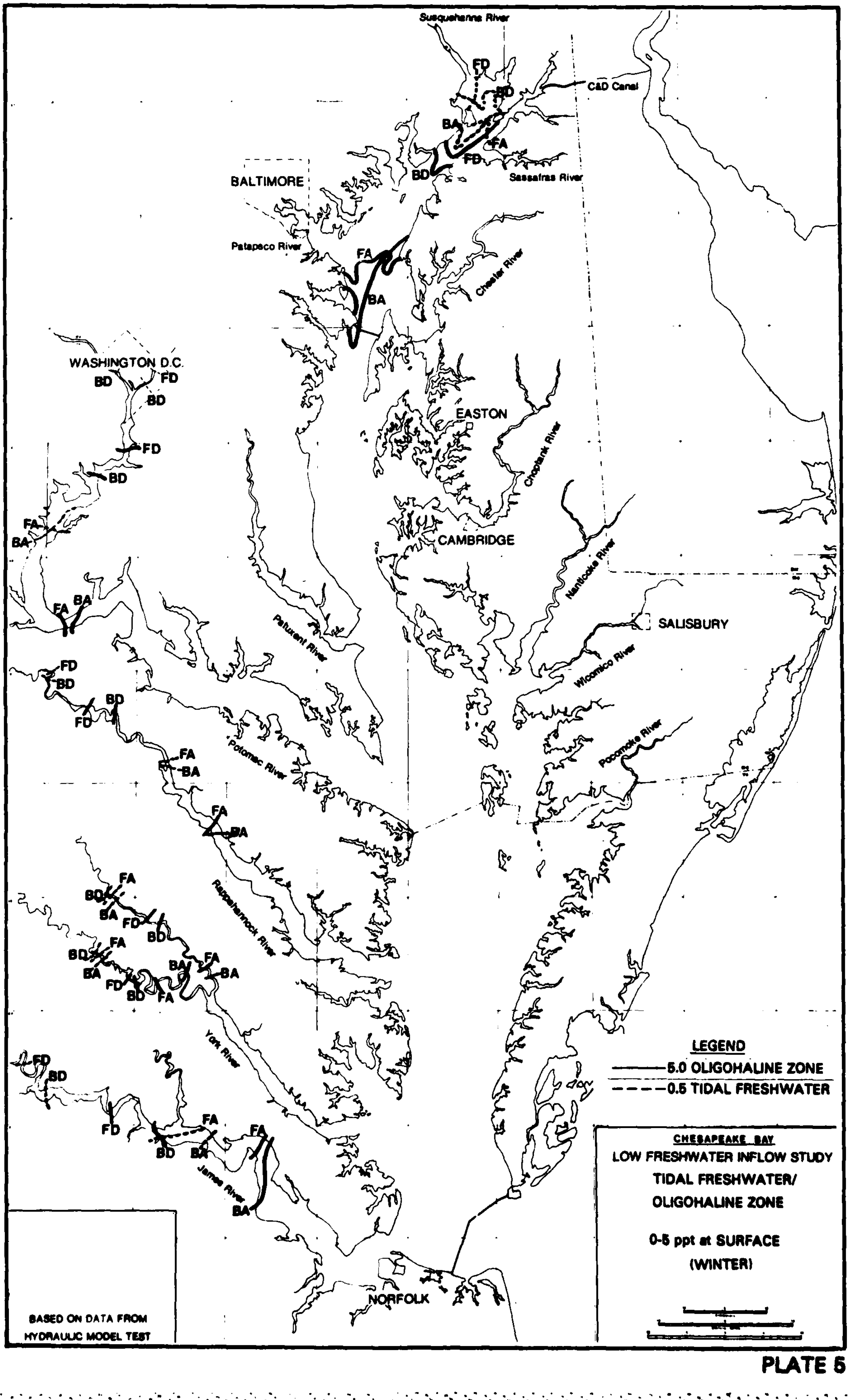

Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
Patapsco River
Chester River
WASHINGTON D.C.
EASTON
Choptank River
CAMBRIDGE
Nanticoke River
SALISBURY
Wicomico River
Patuxent River
Potomac River
Pocomoke River
Rappahannock River
York River
James River
NORFOLK
FD
BD
FA
BA
LEGEND
5.0 OLIGOHALINE
0.5 TIDAL FRESHWATER
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
TIDAL FRESHWATER/
OLIGOHALINE ZONE
0-5ppt at SURFACE
(SUMMER)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 3



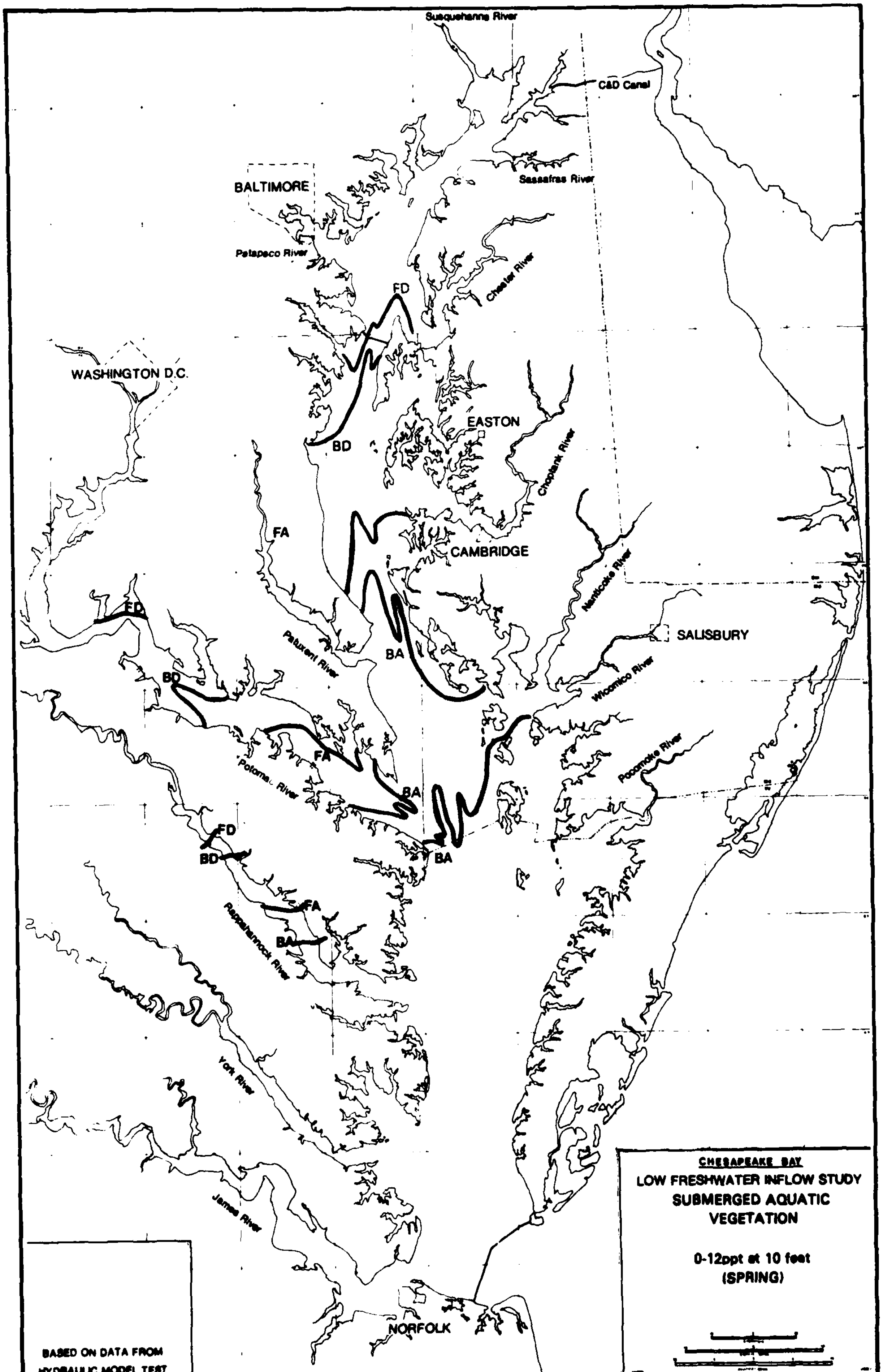
Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
Patapsco River
Chester River
WASHINGTON D.C.
EASTON
Choptank River
CAMBRIDGE
Nanticoke River
SALISBURY
Wicomico River
Patuxent River
Potomac River
Pocomoke River
Rappahannock River
York River
James River
NORFOLK
FD
BD
FA
BA
LEGEND
5.0 OLIGOHALINE ZONE
0.5 TIDAL FRESHWATER
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
TIDAL FRESHWATER/
OLIGOHALINE ZONE
0-5ppt at SURFACE
(FALL)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 4



Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
Patapsco River
Chester River
WASHINGTON D.C.
EASTON
Choptank River
CAMBRIDGE
Nanticoke River
SALISBURY
Patuxent River
Wicomico River
Potomac River
Pocomoke River
Rappahannock River
York River
James River
NORFOLK
FD
BD
FA
BA
LEGEND
5.0 OLIGOHALINE ZONE
0.5 TIDAL FRESHWATER
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
TIDAL FRESHWATER/
OLIGOHALINE ZONE
0-5 ppt at SURFACE
(WINTER)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 5


Susquehanna River
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Sassafras River
BALTIMORE
Patapsco River
Chester River
FD
WASHINGTON D.C.
EASTON
BD
Choptank River
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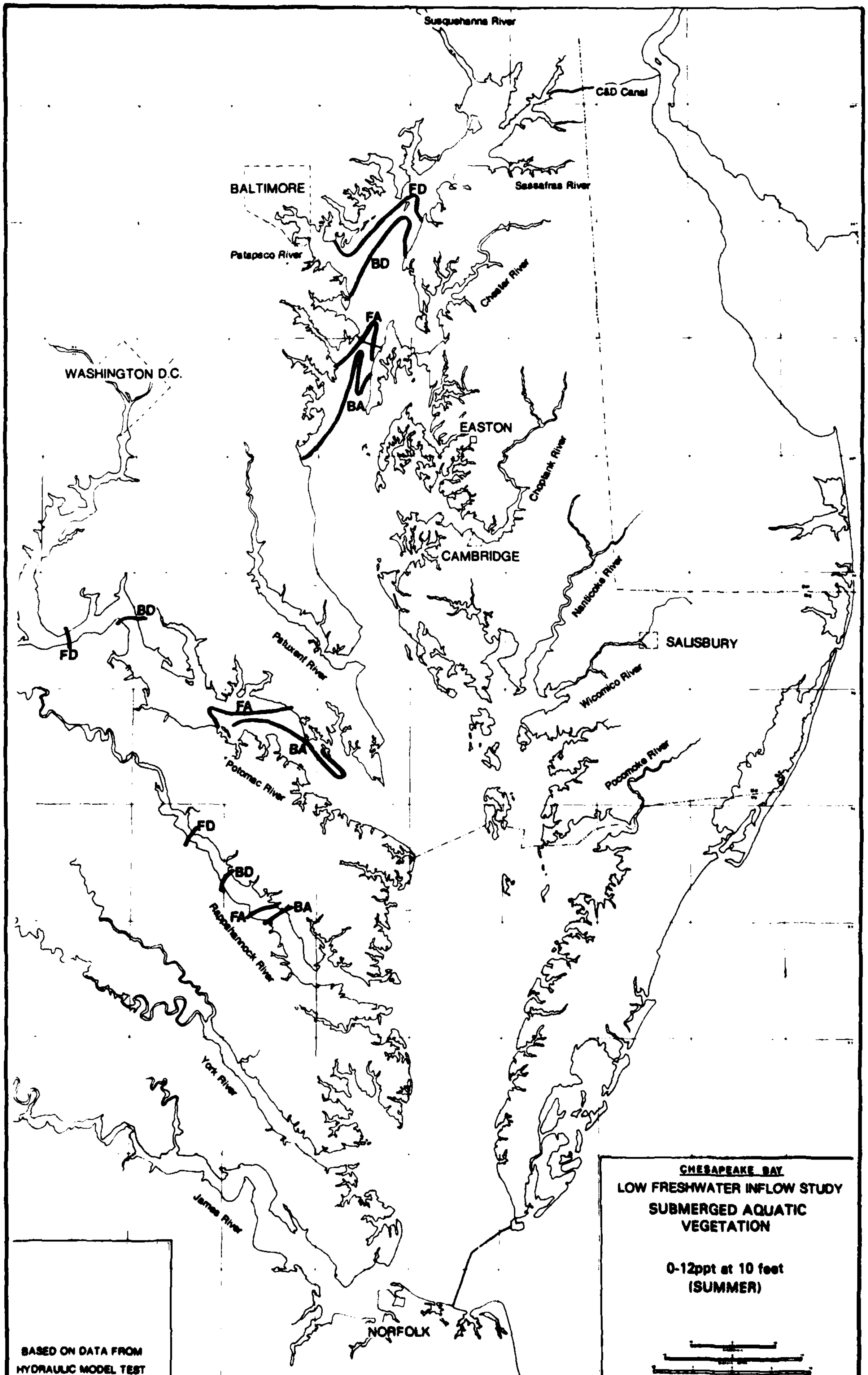
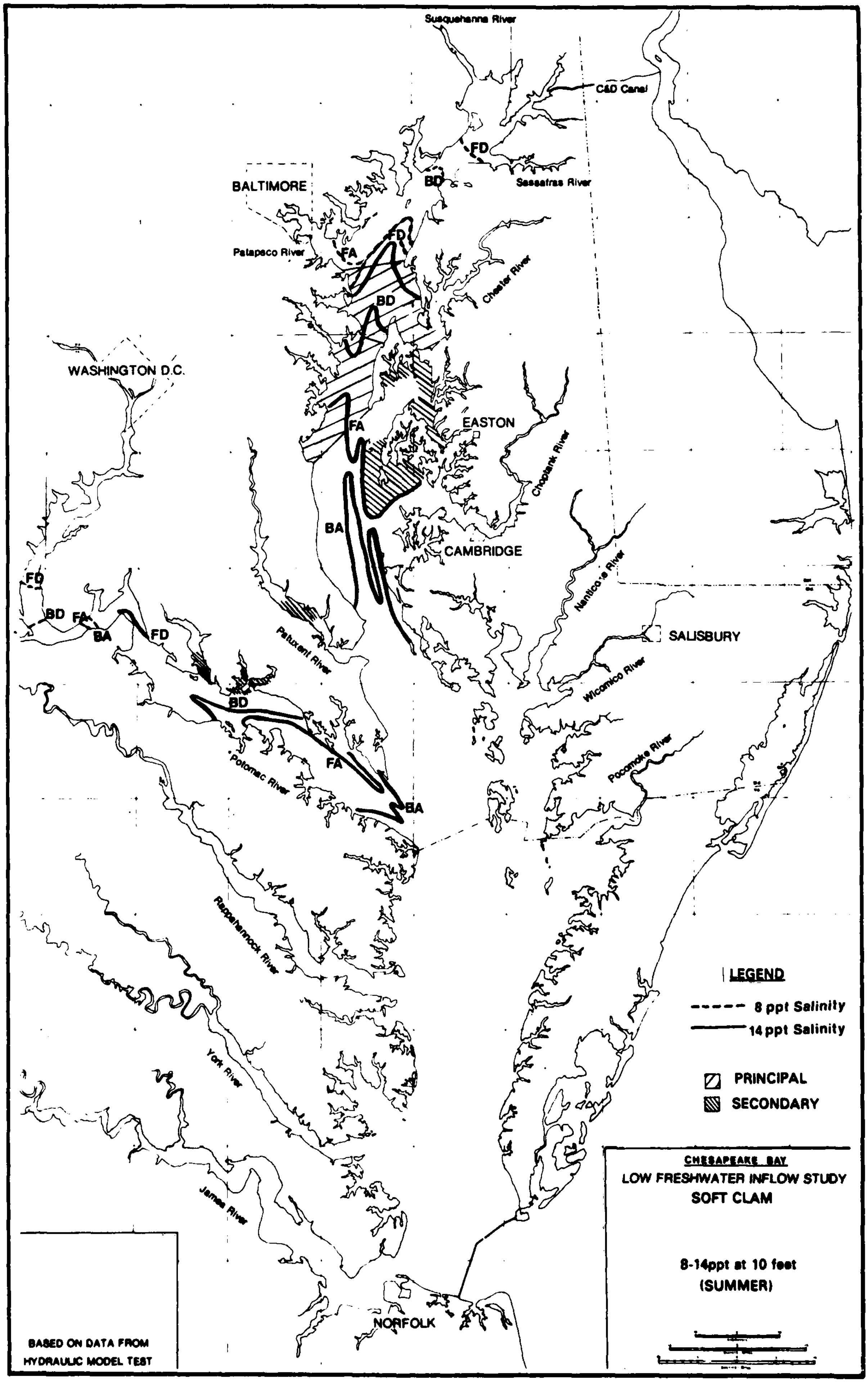
CAMBRIDGE
Nanticoke River
FD
SALISBURY
Patuxent River
BA
BD
Wicomico River
FA
Potomac River
BA
Pocomoke River
FD
BD
BA
FA
Rappahannock River
BA
York River
James River
NORFOLK
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
SUBMERGED AQUATIC VEGETATION
0-12ppt at 10 feet
(SPRING)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 6



Susquehanna River
C&D Canal
Sassafras River
BALTIMORE
FD
Patapsco River
BD
Chester River
FA
BA
WASHINGTON D.C.
EASTON
Choptank River
CAMBRIDGE
Nanticoke River
SALISBURY
BD
FD
Patuxent River
Wicomico River
FA
BA
Potomac River
Pocomoke River
FD
BD
FA
BA
Rappahannock River
York River
James River
NORFOLK
BASED ON DATA FROM
HYDRAULIC MODEL TEST
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
SUBMERGED AQUATIC
VEGETATION
0-12ppt at 10 feet
(SUMMER)

PLATE 7


Susquehanna River
C&D Canal
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BD
Sassafras River
BALTIMORE
Patapsco River
FA
FD
BD
Chester River
WASHINGTON D.C.
FA
EASTON
Choptank River
BA
CAMBRIDGE
Nanticoke River
FD
BD
FA
BA
FD
Patuxent River
SALISBURY
Wicomico River
BD
FA
Potomac River
BA
Pocomoke River
Rappahannock River
York River
James River
NORFOLK
LEGEND
8 ppt Salinity
14 ppt Salinity
PRINCIPAL
SECONDARY
CHESAPEAKE BAY
LOW FRESHWATER INFLOW STUDY
SOFT CLAM
8-14ppt at 10 feet
(SUMMER)
BASED ON DATA FROM
HYDRAULIC MODEL TEST

PLATE 8

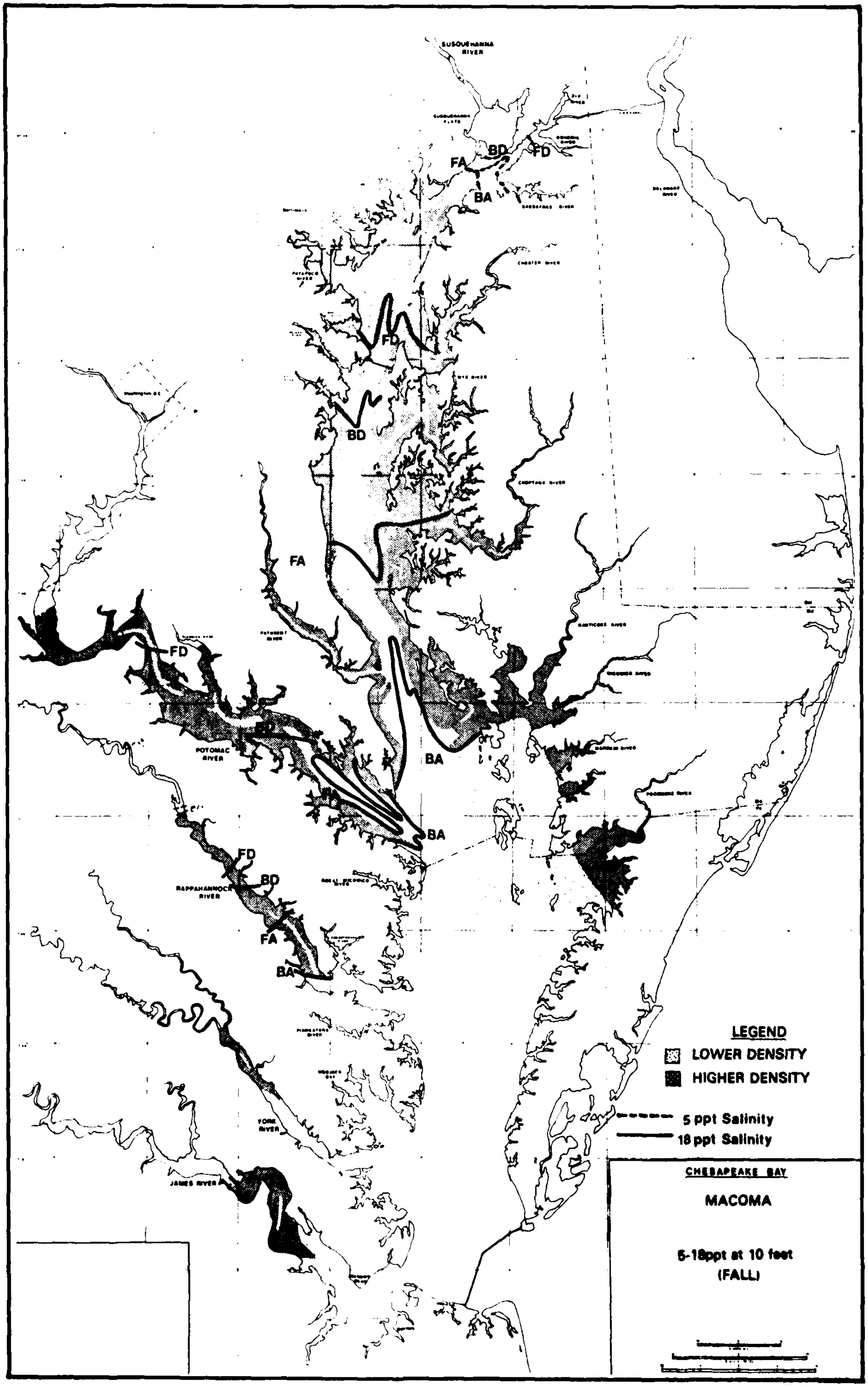
SUSQUEHANNA RIVER
FA
BD
FD
BA
CHESTER RIVER
FD
BD
CHOPTANK RIVER
FA
FD
POTOMAC RIVER
FD
FA
BA
BA
FD
BD
RAPPAHANNOCK RIVER
FA
BA
YORK RIVER
JAMES RIVER
LEGEND
LOWER DENSITY
HIGHER DENSITY
5 ppt Salinity
18 ppt Salinity
CHESAPEAKE BAY
MACOMA
5-18ppt at 10 feet
(FALL)

PLATE 9

END

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